ECONOMIC COMPARISON OF A NUCLEAR POWERED AND FOSSIL FUELED CONTAINER SHIP

by

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I. INTRODUCTION

Ship development throughout history has been erratic, having been extremely slow during some periods and surprisingly fast at other times. Resistance to technological advances has retarded many ship improvements. The United States throughout its maritime history has shown great foresight with innovations and technological improvements, but then failed to carry on their development, leaving others to reap the advantages of these developments. The nation has failed to provide our merchant marine the steady attention it should receive. Our impressive periods were those when circumstances seemed most severe and unfavorable. Our too frequent lapses have been caused not by opposition, but by loss of interest, indifference, and attention to other things.

This is a time when ship development is proceeding rapidly. World trade has been expanding as a result of population growth and industrialization of underdeveloped countries. To meet this expanding trade, the productivity of ships has been increased. This has been accomplished by an increase in ship's speed and size along with innovations in cargo handling such as containerization, the LASH system, and the intermodial concept.

The increase in speed and size has necessitated an increase in the power required. However, improvements in marine power plants have not kept pace with improvements in the other areas. Although marine nuclear propulsion has been in use since the launching of the U.S.S. NAUTILUS, there is not a nuclear powered U.S. merchant ship in service

today. The reason for this is mainly economic. In the past, with the low power levels and low fossil fuel cost, the higher capital cost of the nuclear power plant has not been outweighed by lower nuclear fuel cost. However, with the higher power requirements and higher fossil fuel cost today and in the future, serious consideration must be given to nuclear propulsion systems.

This paper will compare the economic aspects of one application of marine nuclear propulsion. Chosen for this study was the Sea-Land Service containership SL-7, a modern, high speed, high horsepower, quick turn around vessel.

It is the objective of this study to make as few assumptions as feasible, while at the same time presenting as realistic a situation as possible. Because the nuclear propulsion system is the challenger, all data will be conservatively chosen to favor the fossil fueled ship. Most areas of expense will be examined and appropriate values assigned. Two separate economic criteria will be used to analyze the ships so as not to inadvertently favor one or the other alternative through inappropriate selection of criteria.

II. PERSPECTIVE

The era of commercial steam navigation began with the launching of Robert Fulton's CLERMONT in 1807. In 1819 the steam auxiliary powered sailing ship SAVANNAH made the first transatlantic passage using her engine 80 hours out of the 29-day voyage from Savannah, Georgia to Liverpool, England. However, that was the last to be heard of the American pioneering effort in the application of marine steam propulsion. It was left to the British to develop and refine steam propulsion, and in so doing, to dominate world merchant shipping for over 75 years.

Another new era in marine propulsion began with the launching of the N.S. SAVANNAH in July, 1959, the era of commercial marine nuclear propulsion. The ship was constructed by the government as a result of a proposal by President Eisenhower as part of his Atoms for Peace Program.

The SAVANNAH was operated by the State Marine Line from May, 1962 until March, 1963. As the result of a labor dispute, a new general agent, American Export Isbrandtsen Lines, was named. In 1964, the ship made her first transatlantic crossing. After steaming 89,818 miles and visiting 46 ports on demonstration voyages, she was placed in commercial service in August, 1965. By July, 1970 the SAVANNAH had carried cargo on a commercial basis to 37 foreign and 13 domestic ports, and had sailed to the Far East three times. The ship had made a total of 737 reactor start-ups, steamed 454,675 miles with a reactor plant at sea availability of 99.8%, meeting all advanced schedules without a single plant failure.

Although she was not designed to be economically competitive, the SAVANNAH program did accomplish the following:

1. Proved the technical feasibility and safety of a nuclear powered merchant ship.
2. Won acceptance at home and in most foreign ports.
3. Demonstrated the capability of a nuclear powered ship to maintain schedules.
4. Established a servicing facility for future nuclear powered ships at Galveston, Texas.
5. Established a training program for future ship operators.
6. Made practical the development of numerous technical studies to explore the future use of nuclear propulsion.
7. Provided knowledge concerning the economics of nuclear ships.

By 1971 the SAVANNAH had achieved her mission. Because she was not economically competitive, Congress was unwilling to continue supporting her operation. She has thus been taken out of service.

As a result, the only remaining nuclear powered merchant ship in operation was the German ore carrier, N.S. OTTO HAHN. This ship was built in 1968 with the Babcock and Wilcox designed CNSG I (Consolidated Nuclear Steam Generator) licensed to Germany in 1966. By mid 1970 the OTTO HAHN had steamed over 70,000 miles with a reactor plant at sea availability of almost 100%. She demonstrated the suitability of the CNSG design for marine propulsion.

Both Germany and Japan are vigorously pursuing a nuclear merchant ship development program. The U.S. Maritime Administration is sponsoring the development by Babcock and Wilcox and General Electric of a complete nuclear propulsion system with a scheduled completion date

in the summer of 1973. However, there are not at present any plans for the construction of an American nuclear powered merchant ship. The question must then be asked if the name SAVANNAH will represent another time when the United States fails to carry on the development effort it pioneered.

III. ECONOMIC CRITERIA

To make a selection between opposing transport systems necessarily requires the selection of proper economic criteria. The criteria must take into account the true cost of money to the company making the decision, the effect of taxes, both State and Federal, and the particular systems under consideration, while at the same time making as few assumptions as possible.

Because this paper is a comparison of propulsion systems for use in essentially the same ship, the revenue produced by each ship will be equal. Thus, the profit will be the greatest over the ship's life when the total cost of operating the ship over its life is the minimum. The alternative with the lowest average annual cost is then the one that will provide the highest profit, and therefore is the most desirable from an economic standpoint.

Average Annual Cost

The average annual cost (AAC) or required average annual revenue to operate the system includes the daily operating costs, the cost of capital recovery, corporate profit taxes, both State and Federal, and an after-tax profit. The average annual cost is then:[1]

AAC = Average annual cost

AAOC = Average annual operating cost

CC = Construction cost at the start of operations

CRF(x,DT) = Capital recovery factor, including taxes, at rate x, for DT years

x = Effective cost of money

n = Life of the ship in years

DT = Time in which the ship is depreciated

CAOC = Cumulative present worth of the annual operating costs at the start of operations

CRF'(x,n) = The capital recovery factor, excluding taxes, at rate x for n years

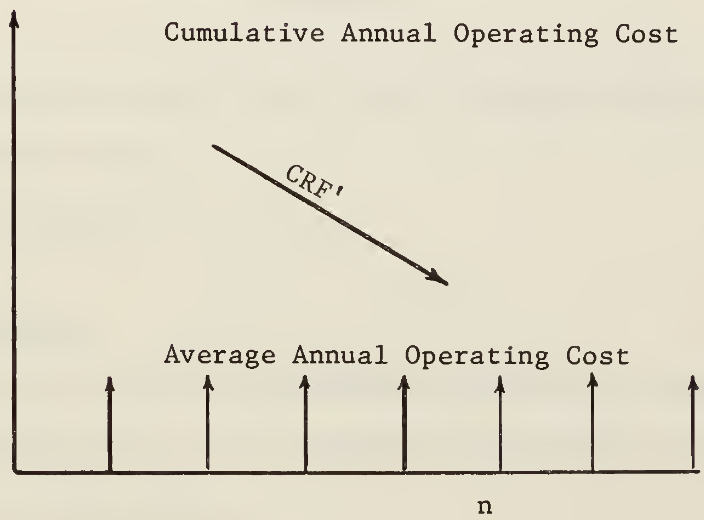
AOC(t) = Annual operating cost for year t

PWF(x,t) = Present worth factor at rate x for t years

$$AAC = AAOC + (CC)CRF(x,DT) \qquad (3\text{-}1)$$

The value of the AAOC is obtained as follows:

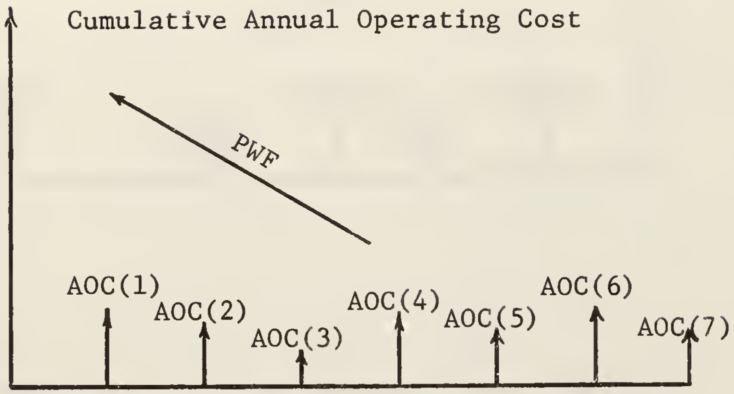
$$AAOC = (CAOC)CRF'(x,n) \text{ (See Figure 3-1)} \qquad (3\text{-}2)$$



Application of the Capital Recovery Factor

FIGURE 3-1

$$\text{CAOC} = \sum_t \text{AOC}(t)\text{PWF}(x,t) \quad \text{(See Figure 3-2)} \qquad (3\text{-}3)$$



Application of the Present Worth Factor

FIGURE 3-2

The present worth factor can be obtained from tables or calculated as follows:

$$\text{PWF}(x,t) = (1 + x)^{-t} \qquad (3\text{-}4)$$

<u>Construction Cost</u>

The value of CC is obtained by summing the present worth, at the start of operations, of all individual construction cost payments, over the time of construction:

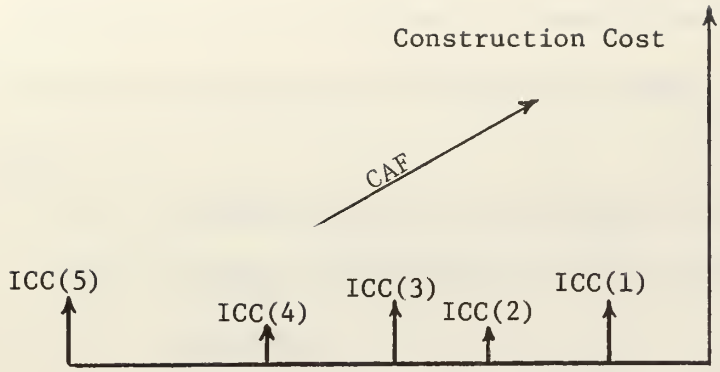
CAF(x,t) = The compound amount factor a rate x for time t

ICC(t) = Individual construction cost payment at time t

$$\text{CC} = \sum_t \text{ICC}(t)\text{CAF}(x,t) \quad \text{(See Figure 3-3)}$$

[illegible]

[illegible]



Application of the Compound Amount Factor

FIGURE 3-3

The compound amount factor can be obtained from tables or computed using:

$$CAF(x,t) \quad = \quad (1 + x)^t$$

By defining all time prior to the start of operations as negative and all time subsequent to the start of operations as positive, CC can then be defined as follows:

$$CC \qquad = \sum_t ICC(t)PWF(x,t)$$

In the above equation t is negative.

<u>Capital Recovery Factor</u>

The capital recovery factor, CRF'(x,t), is a number that when multiplied by the present value of some quantity, such as a mortgage or the value of a ship, will result in the average annual return required, at rate x for t years, to pay off the mortgage. The CRF'(x,t) assumes no salvage value and does not include income taxes.

The CRF'(x,t) can be derived by summing the present worth, at time t = o, of the average annual return over time t, then proceeding as follows:[2]

P = Present value of the mortgage or ship

R' = Average annual return required after taxes have been deducted

R = Average annual return before taxes have been deducted

n = Life of the ship in years

r = Effective income tax rate

$$P = (R')PWF(x,1) + (R')PWF(x,2) + (R')PWF(x,3) + \ldots + (R')PWF(x,t)$$

Let $w^t = PWF(x,t) = (1 + x)^{-t}$

$$P = R'w + R'w^2 + R'w^3 + \ldots + R'w^t$$

$$P = R'w(1 + w + w^2 + w^3 + \ldots + w^{t-1})$$

Multiplying both sides of the equation by w:

$$wP = R'w(w + w^2 + w^3 + \ldots + w^t)$$

Subtracting

$$wP - P = R'w(w^t - 1)$$

$$\frac{R'}{P} = \frac{1 - w}{w(1 - w^t)} = \frac{x}{1-(1 + x)^{-t}}$$

Then by definition of the capital recovery factor:

$$CRF'(x,t) = \frac{R'}{P} = \frac{x}{1 -(1 + x)^{-t}} \tag{3-7}$$

The CRF'(x,t) must now be modified to account for the added cost of income taxes so that the resulting average annual return is large enough to include all the cost included in R' plus income taxes. The CFR'(x,t) will be modified as follows:[3]

Assuming a straight line depreciation for tax purposes, the depreciation would equal P/n.

Annual taxes equal the tax rate times the annual return before taxes less the depreciation:

$$\text{Annual Taxes} = r(R - P/n)$$

$$R = R' + \text{Annual Taxes}$$

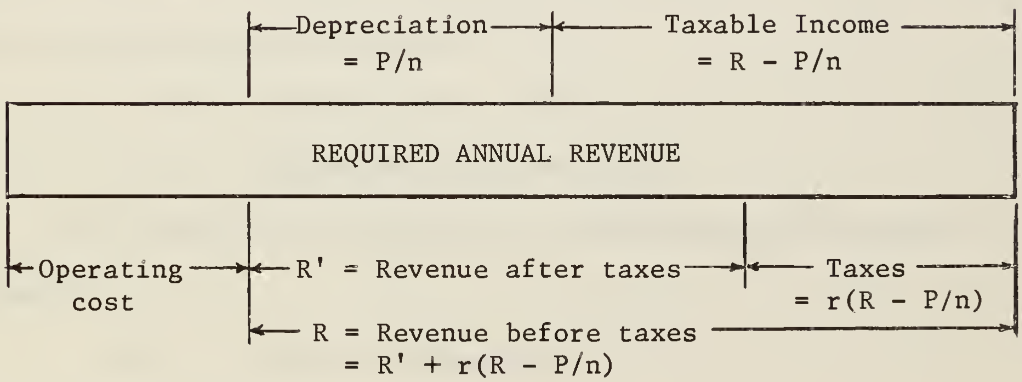
$$R = R' + r(R - P/n)$$

$$R = \frac{R' - rP/n}{1 - r}$$

$$\frac{R}{P} = \frac{R'/P - r/n}{1 - r}$$

$$CRF(x,t) = \frac{CRF'(x,t) - r/n}{1 - r} \qquad (3\text{-}8)$$

Figure 3-4 depicts the division of revenue discussed above.



Division of Revenue[1]

FIGURE 3-4

<u>Cost of Money</u>

To obtain the true cost of money, x, the capitalization structure of the company must be considered. Capital is raised through borrowing from a bank or other institution, the sale of bonds, and the sale of stocks. The bank loan and bonds require a certain interest rate of return. To be able to sell stock requires the company to have a sufficiently high equity return rate to make the investment attractive to the public. The direct cost of money can then be represented as:

a = Direct cost of money

j = The bank or bond interest rate

b = Debt to capital ratio for the company

i = Equity return rate after corporate taxes have been deducted

$$a = jb + i\,(1 - b)$$

The effective cost of money is then the direct cost of money less the savings in income tax due to the deductible nature of the interest on the bank loans or bonds:[4]

$$x = jb + i(1 - b) - jbr \qquad (3\text{-}9)$$

r = Effective income tax rate

The value of r is derived for a Pennsylvania corporation as follows:[5]

FIT = Federal Income Tax

SIT = State Income Tax

TIF = Taxable Income Federal

TIS = Taxable Income State

NOLD = Net Operating Loss Deduction

$$FIT = .48(TIF - NOLD) - \$6{,}500.00$$

$$SIT = .12(TIS)$$

$$TIS = TIF + SIT$$

$$SIT = .12(TIF + SIT)$$

$$SIT = .136364(TIF)$$

$$\text{Total Income Tax} = FIT + SIT$$

$$\text{Total Income Tax} = .616364(TIF) - .48NOLD - \$6{,}500$$

If the company suffers no net operating loss, and if the TIF is large in comparison to the $6,500, the effective income tax rate can be simplified to:

$$r = .616364$$

<u>Nuclear Fuel Cost</u>

To calculate the average annual operating cost, AAOC, requires the calculation of each year's operating cost, AOC. The AOC includes the fuel cost. For the fossil fueled ship the fuel cost is simply added to the other costs for the year to obtain the AOC. However, nuclear fuel costs involve more detailed computations for the core is a large capital investment that will depreciate over a lifetime of approximately four to five years, and will have a salvage value. To determine the average annual cost of the fuel over its operating lifetime requires the following modification to the capital recovery factor to account for the cores salvage value:

Z_O = Cost of fuel at start up

Z_L = Value of fuel at shut down

$CRFS'(x,n)$ = Capital recovery factor with a salvage value excluding taxes, at rate x for n years

AF' = Average annual fuel cost excluding taxes

L = Life of the core in years

Performing the same sequence of steps as done in the derivation of equation (3-7):

$$Z_O = (AF')PWF(x,1) + (AF')PWF(x,2) + \ldots + (AF')PWF(x,L) + (Z_L)PWF(x,L)$$

$$Z_o = AF'w + AF'w^2 + AF'w^3 + \ldots + AF'w^n + Z_L w^n$$

$$Z_o = \frac{AF'(1 - w^L)}{x} + Z_L w^L$$

$$(1 - w^L)AF' = (Z_o - Z_L)x + Z_L(1 - w^L)x$$

$$AF' = \frac{(Z_o - Z_L)x}{1-(1 + x)^{-L}} + xZ_L$$

$$AF' = (Z_o - Z_L)CRF(x,L) + xZ_L$$

$$\frac{AF'}{Z_o - Z_L} = CRF'(x,L) + \frac{xZ_L}{Z_o - Z_L}$$

$$CRFS'(x,L) = CRF'(x,L) + \frac{xZ_L}{Z_o - Z_L} \qquad (3\text{-}11)$$

Because the core is a capital investment, corporate taxes must be included in the average annual cost. This will be accomplished by performing the same sequence of steps as in the derivation of equation (3-8):

AF = Average annual fuel cost including taxes

$CRFS(x,L)$ = Capital recovery factor with a salvage value including taxes

The straight line depreciation equals $(Z_o - Z_L)/L$

$$\text{Annual Taxes} = r(AF - (Z_o - Z_L)/L)$$

$$AF = AF' + \text{Annual Taxes}$$

$$AF = \frac{AF'}{1 - r} - \frac{r(Z_o - Z_L)}{L(1 - r)}$$

$$\frac{AF}{Z_o - Z_L} = \frac{AF'}{(1 - r)(Z_o - Z_L)} - \frac{r}{L(1 - r)}$$

$$CRFS(x,L) = \frac{CRFS'(x,L)}{1 - r} - \frac{r}{L(1 - r)} \qquad (3\text{-}12)$$

$$AF = (Z_o - Z_L)CRFS(x,L)$$

The preceding criteria will provide an accurate comparison between the alternative power plants under discussion, for the criteria includes all the important factors that effect the cost of operating the ships, while at the same time requiring as few assumptions as possible.

The data assumed for this study is listed in Table 3-1. A sensitivity analysis will be performed by varying different parameters around this base data.

Table 3-1

ECONOMIC DATA

i	=	After tax equity return	=	.12
j	=	Interest rate	=	.09
b	=	Debt to capital ratio	=	.75
r	=	Effective income tax rate	=	.616364

Average Annual Net Profit

To insure that the average annual cost criteria does not favor either alternative, a second criteria, the average annual net profit (AANP), will also be employed. Although this requires additional assumptions, in that the revenue generated by the ship must be predicted, the

criteria is necessary to observe the effect of the lost revenue that results when the nuclear powered ship is refueled. The average annual net profit is derived as follows:

AANP = Average annual net profit

ANP(t) = Annual net profit, year t

TI(t) = Taxable income, year t

RPY(t) = Revenue per year, year t

AOC(t) = Annual operating cost, year t

DA = Straight line depreciation

J(t) = Total interest payment, year t

RPC = Revenue per container

CPV = Containers carried per voyage

VPY = Number of voyages per year

$$AANP = CRF'(x,n)\sum_{t} ANP(t)PWF(x,t)$$

$$ANP(t) = TI(t)(1 - r)$$

$$TI(t) = RPY(t) - AOC(t) - DA - J(t)$$

$$RPY(t) = (RPC)(CPV)(VPY)$$

$$DA = CC/DT$$

$$J(t) = (CC - (t - 1)DA)bj$$

IV. THE SHIP

In order to conform to the objective of minimizing the number of assumptions, it was necessary to use an existing containership and to modify it as required to accommodate the nuclear power plant. The ship chosen was the SL-7 design of Sea-Land Service, Inc. Eight of these ships are under construction or in operation. The SL-7 is a modern, high horsepower, high speed, 33 knot, fast turn around containership. The ship has twin-screw, steam turbine propulsion. Each screw is turned by a 60,000 SHP cross compounded turbine connected through a double reduction gear. Each turbine is supplied by a boiler producing steam at 850 psig and 955 degrees Fahrenheit.

Electrical power generating equipment consists of two 3,000 KW turbine driven generators, one 1,500 KW standby diesel generator, and one 60 KW emergency diesel generator.

The containers are carried in fifteen groups of container cells in five holds forward and four holds aft of the engine room. All cells will accommodate 35 ft. containers. In addition, the hold immediately forward of the engine room can carry 40 ft. containers. The hatches are designed to carry containers three tiers high. The two forward holds will not carry containers, but are suitable for general cargo or vehicles[6].

The design of the ship is such that water ballast is required for stability under most load conditions. When underway, the fuel oil consumed must be replaced by water ballast. To meet the increasing

pollution control requirements, separate tanks are used for the fuel oil and water ballast. Because of this the ship cannot carry sufficient fuel oil to operate on Trade Route 12 (East Coast of the United States to the Far East) at design speed. However, the ship can and probably will operate on Trade Route 4 (East Coast of the United States to the West Coast of the United States to the Far East).

The Nuclear Powered Ship

The nuclear version of the SL-7 will be designated as the SL-7N for this study.

To adapt the SL-7 for nuclear propulsion will require some modifications to accommodate the nuclear power plant and to meet American Bureau of Shipping and United States Coast Guard requirements.

According to the American Bureau of Shipping's, *Guide for Classification of Nuclear Ships*, Chapter 2-4, "The ship should be capable of remaining afloat with positive stability when two adjacent main watertight compartments are flooded."

The SL-7 does not meet this requirement for the machinery space. If the machinery space and an adjacent compartment are flooded, the ship loses positive stability. To meet the two compartment standard for the SL-7N, the machinery space will be divided into two compartments, the reactor compartment and the engine room.

The SL-7N will also be propelled by two 60,000 SHP cross compounded turbines connected through double reduction gears to their respective shafts. Electrical power will be supplied by two 3,000 KW turbine drive generators. However, the steam supplied will be only slightly superheated at 575 degrees Fahrenheit and 700 psi. This will

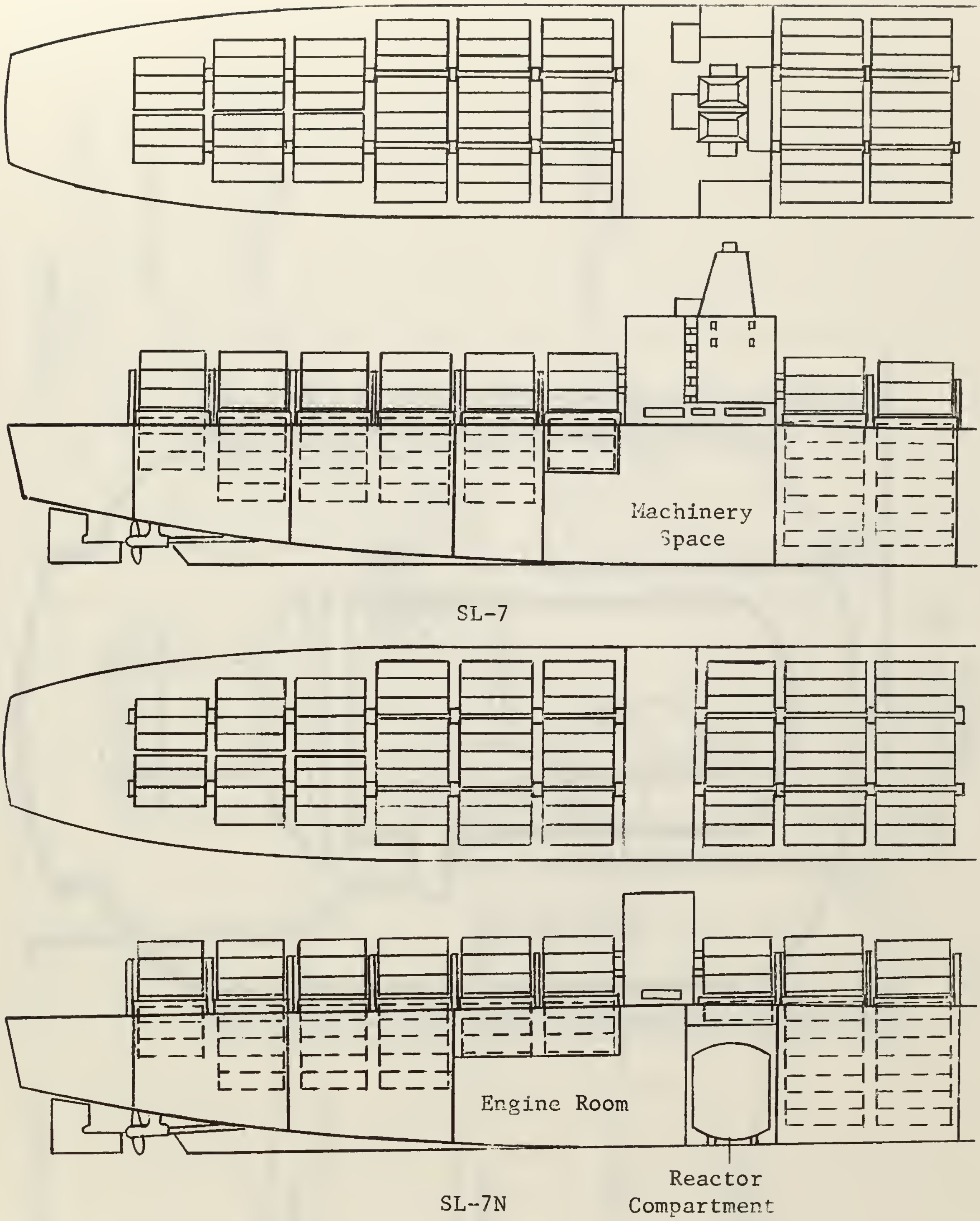
require larger turbines and a moisture separator to be located between the high and low pressure units of the main turbines. In addition, to meet in port safety requirements, a means of moving the ship without the reactor is required. This is accomplished by providing two 1,500 HP electric motors, one connected through a coupling to each reduction gear. Power to these motors will be provided by two stand-by diesel generators.

The machinery space on the SL-7 is 115 ft. long. The length required to accommodate the nuclear steam supply system, the larger steam turbines, the additional diesel generator and the other components not found on the SL-7 requires a machinery space 140 ft. in length.

The additional length, with sufficient height to accommodate the machinery, is obtained by the relocation of the two lower rows of containers in hold 9. These twenty containers can be located on the main deck above the reactor compartment in the space on the SL-7 occupied by the upper portion of the machinery casing and the uptakes. This will require some rearrangement of the aft house. Actually thirty to forty containers can be accommodated in this space, however, since this study is based on equal transport capacity, only twenty containers will be carried. See Figure 4-1.

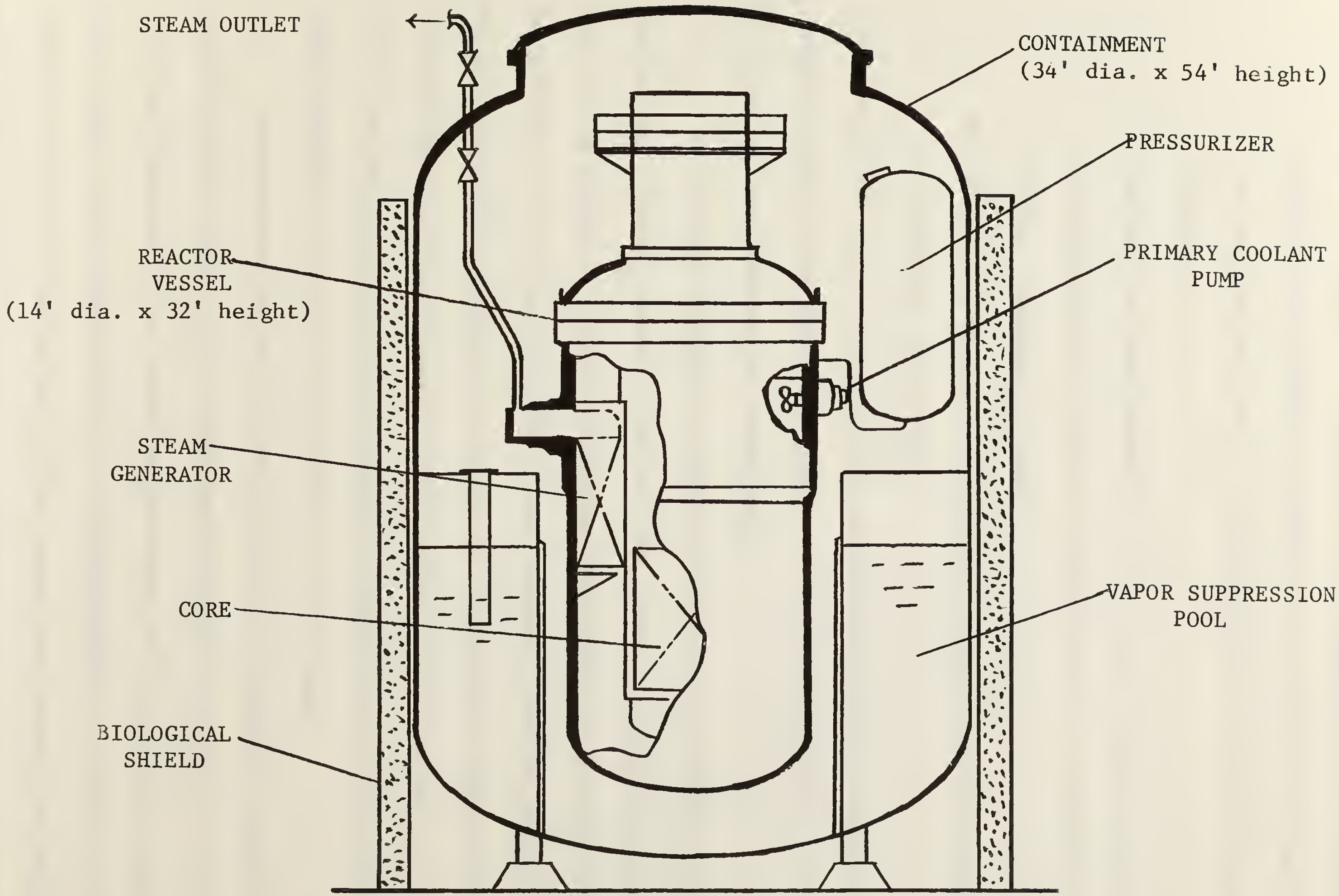
The nuclear steam supply system to be used in this study is the Babcock and Wilcox, Consolidated Nuclear Steam Generator (CNSG IV) design shown in Figure 4-2. The unitized design was selected over the loop type plant used on the SAVANNAH for the following reasons:

1. The amount of space required is reduced.
2. The primary system is smaller therefore the weight of secondary shielding is reduced.



Container Arrangement

FIGURE 4-1



CNSG IV 120,000 shp
FIGURE 4-2

3. Because there are no loops through which to pump the primary coolant, the pumping power requirements are reduced.
4. With no large pipes to rupture, the unitized design is inherently safer, and the safety injection system required is smaller.
5. Radioactive contamination of the system should be less of a problem because there are fewer places for radioactive corrosion products to deposit.
6. Decay heat removal problems are reduced because natural circulation is possible.

This design has been achieved at the expense of a larger, thicker walled pressure vessel. However, this pressure vessel is well within the capability of modern fabrication technology.

In the CNSG design the primary coolant flow is entirely within the reactor pressure vessel. The coolant flows up through the core, where it is heated to about 600 degrees Fahrenheit, to a canned motor driven pump, then it is discharged down through the steam generator, where it is cooled, and back to the core. To keep the primary coolant from boiling requires that the primary system be maintained at 1,850 psig. This is accomplished by use of a separate pressurizer in which electric heaters maintain saturation conditions for 1,850 psig.

The pressure vessel and pressurizer are completely enclosed by the containment vessel. The containment vessel is capable of containing the steam produced by any conceivable rupture of the primary system which might release radioactivity to the environment. A vapor pressure suppression pool is located within the containment vessel and helps reduce the peak pressure seen by the containment in case of a rupture.

This pool also serves as primary shielding to protect personnel against radiation from the core.

Additional shielding surrounds the containment vessel and consists of lead, concrete, steel, and polyethelene.

The unitized design is a proven concept that has been in use for over three years on the OTTO HAHN and has shown an at sea reliability of almost 100%.

In addition to the two compartment requirement, a collision barrier is also required. One of the major safety problems resulting from the use of a nuclear power plant at sea is the potential collision with another vessel causing penetration of the primary system resulting in the release of radioactive material to the environment. To preclude this possibility some means of preventing the striking ship from penetrating the reactor compartment is required. The collision barrier is the solution.

The American Bureau of Shipping has developed interim specific requirements for collision barrier design. The barrier consists of reinforced transverse bulkheads, longitudinal bulkheads, decks, flats, and the double bottom. The design of the SL-7N collision barrier requires heavy plating, up to three inches thick, to be part of the main hull structure. Vertically, reinforced flats are arranged at selected locations. These reinforced flats with the required supports and the foundation of the reactor compartment make an extremely stiff structure.

Advantage will be taken of the additional structural support required for the collision barrier and containment vessel to provide a secondary containment to house the nuclear steam supply system. This will provide additional leaktightness in the event of a nuclear accident.

The enclosure will consist of the forward transverse bulkhead of the machinery space, the transverse bulkhead between the reactor compartment and the engine room which was added to meet the two compartment damage control requirement, and the addition of two longitudinal bulkheads on either side of the secondary shielding.

Foundation design will be similar to, but heavier than that for the SL-7 because of the larger turbines, the additional diesel generator, and the two electric propulsion motors. The major increase in foundation weight is that required for the pressure vessel and containment. Also, protection must be designed into the foundation and inner bottom to minimize the possibility of piercing the containment or seriously displacing nuclear components in the event of grounding.

Table 4-1 lists the ship characteristics. It will be noticed that the combined lightship displacement plus fuel oil capacity for the SL-7 exceeds the lightship displacement of the SL-7N by 2598 LT. If the ship was specifically designed for nuclear propulsion, advantage could be taken of this difference in displacement by reducing the draft or increasing the cargo capacity. However, since stability problems might arise with this particular ship, it is assumed that the SL-7N will be required to take on water ballast and to maintain the same draft as the SL-7.

Figures 4-3 and 4-4 show the Power vs. Speed and the Fuel Consumption vs. Speed characteristics of the SL-7.

Table 4-1

SHIP CHARACTERISTICS

	SL-7	SL-7N
Length, Overall	946.6 ft.	946.6 ft.
Length, Between Perpendiculars	880.5 ft.	880.5 ft.
Beam, Molded	105.5 ft.	105.5 ft.
Depth to Main Deck (Fwd)	64.0 ft.	64.0 ft.
Depth to Main Deck (Aft)	68.5 ft.	68.5 ft.
Draft, Full Load	33.0 ft.	33.0 ft.
Structural Steel	17,640 LT	17,800 LT*
Machinery	3,310 LT**	2,340 LT
NSSS		1,160 LT
Containment and Shielding		1,340 LT
Collision Barrier		1,200 LT
Outfit	2,440 LT	2,440 LT
Lightship Displacement	23,390 LT	26,280 LT
Fuel Capacity (100%)	5,488 LT	
Displacement (Full Load)	48,500 LT	48,500 LT
Cargo Deadweight	21,000 LT	21,000 LT
Diesel Oil	170 LT	340 LT
Stores	100 LT	100 LT
Crew Effects	5 LT	5 LT

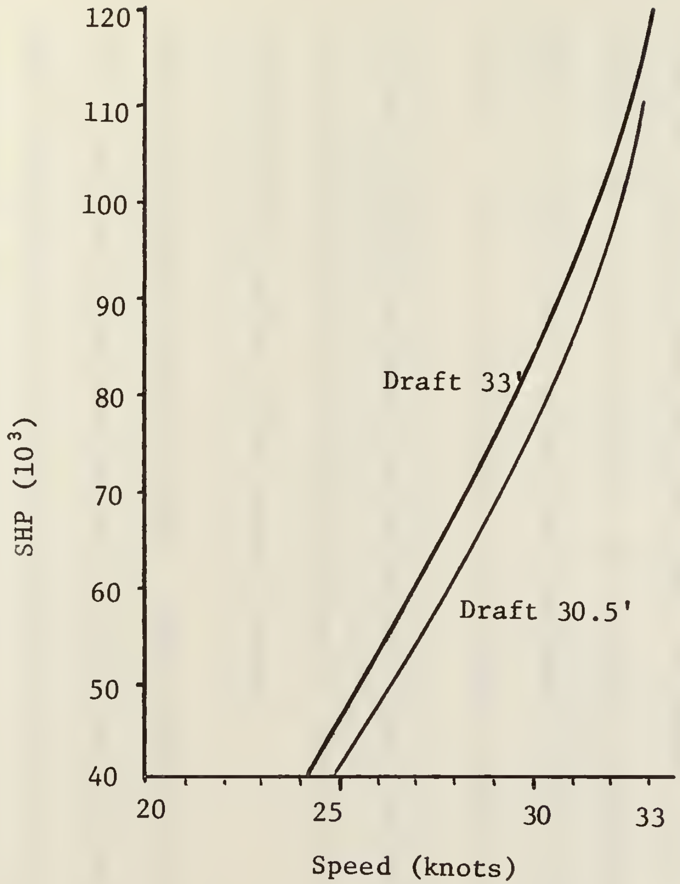
* Includes reactor compartment bulkheads less part of aft deck house removed.

** Includes boilers and support equipment.

Table 4-1 (Cont.)

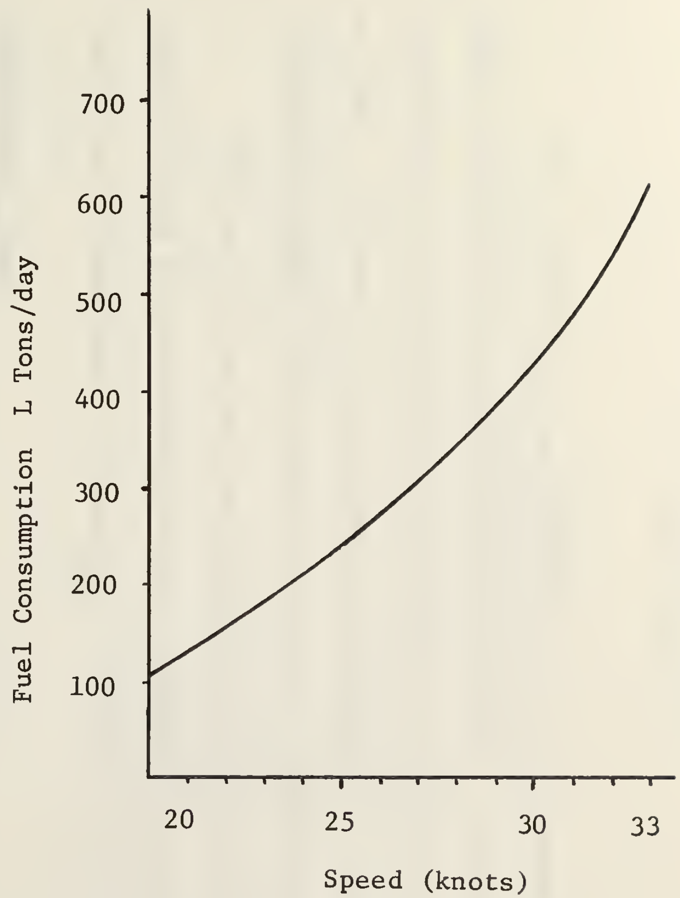
Fresh Water	530 LT	530 LT
Salt Water Ballast	9,561 LT	9,561 LT
Horsepower (Maximum)	120,000	120,000
Number of Shafts	2	2
Speed (Maximum)	33 Kts	33 Kts
Electrical Power	(2) 3,000 KW-TG	(2) 3,000 KW-TG
	(1) 1,500 KW-DG	(2) 2,000 KW-DG
Container Capacity (8 ft. by 8.5 ft. by 35 ft.)		
On Deck	402***	422***
In Cells	694	674
Fuel Rate (LT/Day) / Range (N. Miles)		
33 Kts	614/6,450	
30 Kts	439/8,200	
25 Kts	240/12,500	
In Port	42	
Complement		
Deck	18	18
Engineering	19	20
Steward	13	13
Total	50	51
Accommodations	62	62

*** 102 can be refrigeration containers



Power vs. Speed SL-7

FIGURE 4-3



Fuel Consumption vs. Speed SL-7

FIGURE 4-4

V. ACQUISITION COST

The acquisition cost includes the cost of construction and the owner's pre-delivery cost such as crew training. The construction costs are based on the estimated cost of the SL-7 proposed by General Dynamics in 1968. The costs are escalated at 3% per year for materials and 6% per year for labor. All costs are based on a three ship purchase.

The cost of the hull and machinery for the SL-7N are based on the SL-7 costs and the method of cost estimating outlined in Ref. 7. The nuclear stream supply system cost is based on vendor estimates.

Construction Cost

Construction costs are divided into the following categories:

Hull Structure and Outfit - This includes all hull structure and superstructure with all internal divisional bulkheads. For the SL-7N this includes the collision barrier, the secondary shielding and containment vessel. Outfit items include deck machinery, deck fittings, anchors, windlass, rudder, steering gear, hull piping, and galley equipment.

Machinery - This includes the entire propulsion system from the boilers to the propellers plus auxiliary equipment. The nuclear machinery does not include the nuclear steam supply system,

Nuclear Steam Supply System (NSSS) - This includes the cost of the reactor vessel and internals, pumps, control systems, and auxiliary equipment, excluding the core which is covered under fuel cost, delivered to the shipyard. This item does not include installation cost, which is

included under machinery labor cost.

Table 5-1 summarizes the construction costs.

Table 5-1

CONSTRUCTION COST

Three Ship Buy

	SL-7	SL-7N
HULL STEEL AND OUTFIT		
Material Cost	$12,957,000	$14,117,000*
Labor Cost	15,254,000	17,536,000*
Subtotal	28,211,000	31,653,000
MACHINERY		
Material Cost	18,988,000	14,241,000
Labor Cost	7,702,000	8,642,000**
Subtotal	26,690,000	22,883,000
NUCLEAR STEAM SUPPLY SYSTEM		16,000,000
Total	$54,901,000	$70,536,000

* Includes the collision barrier, secondary shielding, and containment.
** Includes the installation cost of the NSSS.

Construction Schedule

The construction schedules for the SL-7 and SL-7N are listed in Table 5-2. The schedule for the SL-7 is based on their actual construction schedule of from eighteen to twenty-four months. The time for fabrication of the hull of the SL-7N is increased by six months for

installation of the collision barrier, shielding and other additional fabrication. The fifty month manufacturing time for the nuclear steam supply system is based on vendor estimates.

Table 5-2

CONSTRUCTION SCHEDULE

	SL-7		SL-7N	
	Start	Complete	Start	Complete
Prepare Specifications and Obtain Bids	3/75	9/75	1/73	6/73
Order NSSS			6/73	8/77
Order Power Plant	9/75	8/77	6/75	8/77
Fabricate Ship	3/76	9/77	9/75	9/77
Install Core			6/77	8/77
Operational Test of Power Plant	8/77	9/77	8/77	9/77
Sea Trials	9/77	11/77	9/77	11/77
Delivery	1/78		1/78	

Because there have been numerous delays in the construction of utility company nuclear power plants due primarily to environmental questions, the construction time for the SL-7N will be lengthened to observe its effect on costs. It is believed, however, that the present delays in utility company construction will be overcome with the revamping of licensing procedure and the reorganization of the Atomic Energy Commission to handle its increased responsibility in the

environmental area. Therefore, these delays should not effect the SL-7N.

The shipbuilder and power plant vendors receive progress payments based on the percentage of completion. The purchaser retains 10% of the cost as a guarantee against meeting specifications until the guarantee period, which is assumed to be one year for the ship, and two years for the power plant, is over. The pre-delivery payments will be based on a straight line approximation with payments at six month intervals. These payments will be brought forward to ship delivery using the present worth techniques discussed in Chapter III. The construction cost will then be amortized over a twenty year period.

Tables 5-3 and 5-4 show the pre-delivery payment schedule.

Table 5-3

PRE-PAYMENT SCHEDULE SL-7

SHIP		POWER PLANT	
Years Before Ship Delivery	% of Total Cost	Years Before Plant Delivery	% of Total Cost
-1.33	22.5	-1.75	18.0
- .83	22.5	-1.25	18.0
- .33	22.5	- .75	18.0
0.0	22.5	- .25	18.0
+1.0	10.0	0.0	18.0
		+2.0	10.0

Table 5-4

PRE-PAYMENT SCHEDULE SL-7N

SHIP

Years Before Ship Delivery	% of Total Cost
-1.75	18.0
-1.25	18.0
- .75	18.0
- .25	18.0
0.0	18.0
+1.0	10.0

NSSS

Years Before NSSS Delivery	% of Total Cost
-4.0	10.0
-3.5	10.0
-3.0	10.0
-2.5	10.0
-2.0	10.0
-1.5	10.0
-1.0	10.0
- .5	10.0
0.0	10.0
+2.0	10.0

MACHINERY

Years Before Machinery Delivery	% of Total Cost
-2.0	18.0
-1.5	18.0
-1.0	18.0
- .5	18.0
0.0	18.0
+2.0	10.0

Training Cost

Prior to ship delivery the crew must operate the ship during tests and sea trials and must be trained to do so. It is asssumed that the crew is experienced with steam propulsion plants, and that the officers on the SL-7N have received training in nuclear propulsion such as is offered at the Merchant Marine Academy.

For the SL-7N it is assumed that the entire engineering department excluding wipers will be assembled one year prior to delivery to begin training and licensing. The training period will last eight months and is estimated to cost about $300,000. The crew cost, which includes wages and benefits, during this training period would be $312,000.

Only a limited number of engineering department personnel on the SL-7 are assembled six months prior to ship delivery. They include the chief engineer, first assistant, second assistant and three third class assistants. The training period will last two months and will cost about $50,000. The crew cost during this period will be $36,000.

During the tests and sea trials phase, the entire crew will be assembled. The crew cost for this four month period would be:

SL-7	$ 600,000
SL-7N	$ 612,000

The total pre-delivery training and crew cost is then:

SL-7	$ 686,000
SL-7N	$1,224,000

VI. OPERATING EXPENSES

To keep the ship at sea, the owner has a number of expenses in addition to amortization payments and fuel cost. These expenses are discussed below and summarized in Table 6-3. Ref. 8 provided basic cost data for many items in this chapter.

Crew Cost

The crew of the SL-7 will consist of eighteen deck, nineteen engineering and thirteen steward department personnel. The average crew cost including officer and crew wages, subsistence, and fringe benefits in 1971 for Sea-Land was $70 per day plus an additional 50% for overtime[9]. The yearly crew cost in 1971 for the SL-7 would have been $1,916,250.

The crew of the SL-7N will be increased by one for the engineering department. The additional man will be required to handle health physics and water chemistry functions. Similar studies to this one have generally considered that four additional men would be required. However, this was based on a thirteen man engineering force. Because of the nineteen men on the SL-7, only one additional man is required for the SL-7N. The yearly crew cost for the SL-7N is then $1,954,575.

The Office of Maritime Manpower has published data showing that crew wages have risen an average of 6% per year since 1949. This rate of increase is assumed for the life of the ship. The yearly crew cost for the SL-7 in 1978 would then be $2,881,274 and for the SL-7N $2,938,899.

Stores, Supplies and Equipment

This item includes the cost of all consumable stores, supplies and equipment used in maintaining the hull and machinery. For the SL-7 this cost is estimated to be $300 per day in 1978. Using the cost experience of the N.S. SAVANNAH, the projected cost in 1978 for the SL-7N would be $350 per day. This item will be escalated at 3% per year to account for the increasing cost of material.

Maintenance and Repair

Those expenses not covered by insurance which includes repairs to the hull and machinery are included here. Table 6-1 lists these items and the projected cost for 1978.

The Nuclear Steam Supply System maintenance and repair costs are estimated from data on land-based plants to be about .2 mills per SHP/hr in 1967. Using a cost escalation of 4% per year, the 1978 annual maintenance cost would be $200,000.

All items in this category are escalated at 4% per year to account for increases in labor and material cost.

Table 6-1

MAINTENANCE AND REPAIR COST 1978

	SL-7	SL-7N
Hull	$208,000	$208,000
Machinery	100,000	100,000
Boiler	70,000	
Nuclear Steam Supply System		200,000
Drydocking	105,000	105,000
Total	$483,000	$613,000

Insurance Costs

Protection and Indemnity - This insurance protects the company against lawsuits involving the crew, third party, fixed objects, and cargo. This coverage includes:

> Crew - Protects against liability as the result of injury or death of an employee.
>
> Third Party - Protects against liability as the result of injury to persons other than employees who board the ship. This includes longshoremen, maintenance men, etc.
>
> Fixed Object - Protects against damage to piers, navigation aids and other fixed objects.
>
> Cargo - Protects against liabilities relative to damage or loss of cargo.

The cost of this insurance is principally related to the number of crew members, and for 1978 is estimated to be $6.34/man/day. For the SL-7 the annual premium is $115,705 and for the SL-7N it is $118,019.

Protection and indemnity premiums are escalated at 3% per year.

Hull and Machinery - This insurance protects the company from damage or loss of the vessel and is proportional to the value of the ship. The annual premium is estimated to be $10,000 + .007 times the ship's value. The decrease in ship value tends to offset the increase in material and labor cost for repairs and therefore the premium will not be escalated.

War Risk - This insurance becomes effective when the company's normal insurance is terminated at the outbreak of war. It includes protection and indemnity as well as hull insurance. A war risk binder of $250 per

year is carried. This study will assume that war risk insurance is not in effect and therefore will not be considered.

Third Party Nuclear Liability - This insurance is required to protect the company in the event of an accident that results in the release of radioactive materials that cause injury or death to third parties. By projecting the effect of the release of all the radioactive material in a core, which is a very improbable occurance, the resulting loss of life could be tremendous. The amount of third party liability protection required is therefore extensive. Because private insurance companies could not provide all of the coverage, Congress passed the Price-Anderson Act in 1957 to assist utilities in the development of nuclear power plants. The Act provided for government indemnity in excess of available private insurance. In the years since passage, no claim involving indemnity has been received, and a high percentage of the premiums for private insurance that have been held in reserve are being refunded. A limit of $500,000,000 of government indemnification was originally established. This is gradually being reduced as the amount of available private insurance increases. As the Act now stands, it will continue until 1977.

The total amount of insurance now required is $560,000,000; $95,000,000 being supplied by private insurance groups and the remainder by the government. The premium required is broken down as shown in Table 6-2. The total private plus government premium is $359,670 per year. It will be assumed for this study that Price-Anderson protection will be available for the SL-7N as it was for the N.S. SAVANNAH.

Table 6-2

NUCLEAR LIABILITY INSURANCE

Amount of Coverage Private Insurance	Premium Per Million	Premium
1,000,000	48,500	48,500
4,000,000	24,250	97,000
5,000,000	9,700	48,000
10,000,000	4,850	48,500
20,000,000	2,425	48,500
20,000,000	1,212	24,250
35,000,000	1,000	35,000
95,000,000		350,250
Government Insurance $30/MWt		9,420
Total		359,670

Miscellaneous Expenses

This includes all expenses not covered under other categories and is estimated to be $20,000 per year, and to escalate at 3% per year.

Cargo Expenses

Those expenses associated with the storage and handling of cargo. Sea-Land estimates a cost in 1971 of $50 per container. The 1978 cost is estimated to be $100 per container per transit. This item will be escalated at 3% per year to account for that part of the cost

associated with labor. Terminal rents are contracted on a long term basis and will not be escalated.

Administrative and Overhead

The Maritime Administration has compiled data that shows this expense can be directly related to voyage expenses. It includes the cost of management, communications, advertising, survey fees and other expenses not directly accountable to a specific ship. The cost in 1966 was found to average 13% of total voyage expense. This percentage will be used, and since voyage expenses escalate, no separate escalation will be applied to administrative and overhead expenses.

Shore Staff

The nuclear ships will require several people to be included in the shore staff that are not included in the administrative expenses for the conventional ship. This would include a nuclear engineer and a health physicist plus additional training of the existing shore staff. This additional cost is estimated to be for 1978 at $50,000, and to escalate at 6% per year. Table 6-3 shows a summary of the annual operating expenses for 1978 excluding fuel and amortization.

Table 6-3

SUMMARY OF PROJECTED ANNUAL OPERATING EXPENSES 1978

	Escalation Rate (%)	SL-7 $	SL-7N $
Crew Cost	6.0	2,881,274	2,938,899
Insurance			
Protection and Indemnity	3.0	115,705	118,019
Hull and Machinery		394,300	503,700
War Risk		250	250
Nuclear Liability			359,670
Administrative and Overhead		1,261,420	1,355,963
Shore Staff	6.0		50,000
Cargo Expenses	3.0	5,699,200	5,699,200
Store Supply	3.0	109,500	127,750
Maintenance and Repair	4.0	483,000	613,000
Miscellaneous	3.0	20,000	20,000

Operating Schedule

To comply with the criteria specified in the objective of this study requires that a trade route be chosen which is practical and is in actual use or is planned to be used in the near future. The trade route chosen is the one that Sea-Land intends to use for the first of their SL-7's and is on the North Atlantic run, from New York to Rotterdam, to Bremerhaven and then back to New York. A schedule based on

weekly, same day arrivals and departures with minimum in port time is proposed. In port time is dependent on the time to unload and load containers and to fuel the conventional ship. With the modern containership facilities now in existence at these ports, Sea-Land reports that one crane can cycle, that is unload and load, fifteen containers per hour without delays, and that they use three to five cranes per ship. With a 1/3 time allowance for delays, between 720 and 1,200 containers can be cycled per day.

The schedule to be used, Table 6-4, assumes that all containers will be cycled in New York in one day, and that 60% will be cycled in Rotterdam and 40% in Bremerhaven. Resulting in a total of two days required per voyage for cargo handling. An additional day in port will be included to account for any delays such as maintenance and inspections. This time is added to the time in New York, however, it could be spent in any of the ports as required.

An adjustment is made to account for bottom fouling by assuming a .5 knot penalty. That is, only 32.5 knots are obtained at 100% power instead of the designed 33 knots and a power level of 88.3% is required to obtain 31.5 knots instead of the designed 83.3%.

The total time for the transit each way is increased by .3 days to account for bad weather, which is particularly prevalent on the North Atlantic run. Also, three hours are allowed for port entry and exit time.

The total time at sea, 78.6%, is slightly less than the 80% that Sea-Land reports for the rest of its fleet. However, this is to be expected due to the increased speed and subsequent reduction in transit time.

Table 6-4

Operating Schedule

Location	Occurence	Distance Nautical Miles	Speed Knots	Time Days	% Power	Effective Full Power Days
New York	Cargo Handling			2	10	.20
New York	Port Entry and Departure		Maneuvering	.25	20	.05
At Sea	Transiting New York To Rotterdam	3,500	31.5	4.9	88.3	4.33
Rotterdam	Cargo Handling			.6	10	.06
Rotterdam	Port Entry and Departure		Maneuvering	.25	20	.05
At Sea	Transiting Rotterdam To Bremerhaven	250	32.5	.32	100	.32
Bremerhaven	Cargo Handling			.4	10	.04
Bremerhaven	Port Entry and Departure		Maneuvering	.25	20	.05
At Sea	Transiting Bremerhaven To New York	3,650	32.5	5.0	100	5.00
Total		7,400		13.97		10.10

Ship at sea 11 days or 78.6% of time with a power plant utilization of 72.1%.

VII. FOSSIL FUEL

The major advantage of nuclear power is fuel cost. An understanding of fossil fuel and nuclear fuel costs and cost trends is essential to an economic comparison of the two propulsion systems.

The primary fuel oil burned in fossil fuel propulsion plants is the residual oil, Bunker C. The refining process separates the crude oil into various quality products, and the percentage of these products (gasoline, kerosene, diesel oil, etc.) can be changed depending on the demand and the revenues available from each product. Residual oil is the viscous fluid remaining after higher valued products have been removed from the crude oil. Refineries in the United States have reduced the percentage of residual produced to 6% of each barrel of crude oil. Other countries with different demands have different product percentages. In general, European refineries produce a substantially higher percentage of residuals than the United States.

Fuel cost and cost trends must be analyzed both in the United States and foreign ports because the SL-7 will carry sufficient fuel for a one-way voyage only, and therefore will refuel both in this country and in Europe or the Far East. Furthermore, this country's dependence on oil imports, particularly residual oil has become significant and foreign prices affect the United States market.

Although the cost of residual oil is determined by many interdependent factors and cannot be tied directly to the cost of crude oil, it can be assumed that the general cost trends in crude oil will be

paralleled by similar trends in residual oil.

Since 1965 the United States demand for energy has been increasing by greater than 5%/year. Although the United States is the world's largest producer, it is also the largest consumer of petroleum and demand has been outpacing supply. This country imported about 23% of its crude oil requirements in 1971, 13% coming from the Middle East. Even if large quantities of oil from Alaska reach the consumer by 1975, the United States import requirements will continue to increase. United States shale oil offers the possibility for large scale production, however, more research is required and the price of oil will probably have to increase to the $4 to $5 range before shale oil becomes economical[10]. The National Petroleum Council predicts that the United States will depend on foreign sources for more than half of its oil by 1985.

Residual oil consumption in this country far exceeds demand. On the East Coast, regulations permit the unlimited importation of residual oil and about 95% of the residuals consumed in this region are imported, making the East Coast sensitive to the overseas market[11].

In a study conducted by M. W. Kellogg Company for the Environmental Protection Agency on the availability of residual oil, these conclusions were reached:

1. The total world production potential for residual oil, with no sulfur content limit, is sufficient to meet U. S. demand through 1973, but 1974 and 1975 show deficits.
2. The total world supply of residuals of 0-1% sulfur required by the U. S. shows an increasing deficit which in 1975 will be 532,000 barrels per day.

The Kellogg Company said, "It can be concluded with reasonable certainty that the U. S. will experience a chronic residual shortage beginning in 1971 if prompt action is not taken to increase the world supply potential."

Short-term supply methods to increase production will be adequate to meet U. S. demand for the next three or four years. However, the best long-term solution would be to step up production capabilities of Western Hemisphere refineries. To make this expansion easier, it will be necessary to develop:

1. Long-term, stable supply sources for low-sulfur African crudes.
2. Long-term price incentives.
3. Methods for disposition of light petroleum fractions, which are essentially by-products in the Caribbean and South American producing areas[12].

The world consumed twice as much oil during 1970 as it did during 1960. This country is consuming 10-20% more oil than it is replacing through new supplies. 1959 was the last year that domestic exploration was keeping pace with demand. To correct this will require increased exploration. To spur increased exploration will require higher prices. A $.25/bbl increase in early 1971 did not produce the desired result for most oil men feel that the hike did not improve their position of a year earlier due to increased taxes coupled with sharp increases in material and labor costs. Fuel oil prices probably must increase by $.50 to $1 per barrel to spur exploration[13].

The Texas Independent Producers and Royalty Owners Association (TIPRO) has called for a 5% annual increase in the wellhead price of

crude oil. With this rate of increase the 1971 wellhead price of Texas crude of $3.28/bbl would increase to $3.90/bbl in 1975, and $5.13/bbl in 1980. A $.60/bbl increase would be required to restore domestic wellhead prices to the 1959 parity[14].

Dr. Richard Gonzalez, noted oil economist, suggests that if prices in general continue to increase at 3-5% annually, crude price increase should range from 5-7% a year if the required exploration is to be accomplished[13].

The foreign cost of crude oil is now increasing, and the era of relatively low oil prices in Europe and the Far East has apparently ended.

The steadily increasing world wide demand for petroleum has resulted in a change from a buyers' to a sellers' market. Until 1971 the oil companies had been able to keep prices down by dealing with each oil exporting country separately. This changed in 1971 when the Organization of Petroleum Exporting Countries (OPEC) consisting of Iran, Venezuela, Saudi Arabia, Kuwait, Libya, Indonesia, Iraq, Algeria, Abu Dhabi, and Qatar which produce 85% of the oil that moves in world trade, began dealing with the oil companies on a united basis.

In February 1971, Iran, Iraq, Saudi Arabia, Kuwait, Abu Dhabi, and Qatar concluded with the oil companies what is known as the Teheran Agreement. The agreement called for an immediate $.35/bbl increase in the posted price of crude oil at the terminal, with an additional flat increase of $.05/bbl and a 2.5% increase in June 1971, and in January 1973, 1974, and 1975. In addition, the tax rate was increased to 55%.

Although posted prices are usually higher than market prices, they are the base for calculating the amount on which taxes are levied.

The market price will be proportional to the posted price. The direct effect of the agreement on Europe's price was to raise cost 15% immediately and by 25% over the next five years[15].

The same rate of increase can be expected in the Far East. In Japan, two major oil firms announced increases of $.28/bbl after the Teheran Agreement was reached.

Although this agreement was supposed to last until 1975, the revaluation of world currencies in late 1971 resulted in renegotiations. On January 20, 1972 an agreement supplemental to the Teheran Agreement was reached between representatives of the OPEC and the oil companies. The agreement boosted immediately the posted price of Persian Gulf crude oil by 8.49%. With a 55% tax rate, the cost to the oil companies will increase by 4.67%, most of which will be passed on to the customer. In addition, a mechanism was established to account for future price adjustments in monetary exchange rates.

The OPEC is also demanding participation with the oil companies. Talks were held in February 1972 with the Saudi Arabian Minister, resulting in Saudi Arabia obtaining a 20% participation which the Minister stated would eventually increase to 51% then to 100% ownership by the year 2000. In return the oil companies are to receive 20% of the book value of their investment with no consideration of the oil reserves. Other countries are asking for a larger percentage than Saudi Arabia.

Following the Teheran Agreement, negotiations were concluded with Libya and Nigeria in April 1971. The Libya agreement provided for a new base posting of $3.07/bbl with four scheduled increases of $.05/bbl plus 2.5% in March 1971 and in January 1973, 1974, and 1975. In addition, while the Suez Canal is closed, a freight premium of $.12/bbl

plus a variable premium based on tanker freight rates was to be applied. The resulting cost per barrel of crude at the terminal in Libya in mid-1971 was \$3.447 and in Nigeria \$3.422. Assuming the Suez Canal is re-opened by 1975, the price on January 1, 1975 for Libya should be \$3.597[16].

In October, Libya decreed a 3.57% boost in the exchange rate of the Libyan dinar which would apply to all oil company payments. Then in December 1971, Libya nationalized all British Petroleum (BP) holdings. Their delegate to the OPEC said that the takeover was a warning to other Libyan operators to fall in line on additional payments or suffer the same fate. Since then, however, BP has established a successful free world boycott of Libyan oil, and the Libyan government has had difficulty recruiting the technically trained personnel needed to operate the facilities. As a result, Libya has moderated its terms. However, this has not prevented the government from demanding an increase in the posted price similar to, but larger than, the supplemental Teheran Agreement to account for the effect of the revaluation of world currencies.

The only hope of keeping prices from increasing at a high rate is if the OPEC agreement falls apart because one or more of the member nations decides to increase revenues by reducing prices and increasing production. International agreements such as this have in the past, not lasted. Whether this one will is speculative.

Certainly prices will continue to increase. For with the expectation of consumption doubling in the 70's there is little hope that Europe can reduce dependence on OPEC members in the next five to ten years. In addition, escalating labor and material costs must result in

increased prices.

Venezuela, in December 1970, increased the tax rate on oil company profits from 52% to 58%. In 1971 the government revalued the bolivar upward by 2% and increased the posted price on crude oil by \$.26/bbl; this resulted in an average effective increase of Venezuelan crude oil of \$.32/bbl. In addition, rigid production quotas were established which would result in an increased tax if the quotas were not met.

For residuals, the government increased the tax reference price of the .3% sulfur fuel oil from \$3.52/bbl to \$4.35/bbl. With a 58% tax the increase cost to the company is \$.48/bbl. This price has more than doubled from \$1.91/bbl in early 1971 to \$3.596/bbl[17].

In addition, Venezuela has served notice of termination of its trade agreement with the United States. Barring a new agreement or legislation, the tariff on crude oil will be increased by over \$.15/bbl, thus increasing the cost to the customer.

Based on the above discussion, a price increase of 3% a year is believed to be conservative and will be assumed for this study. Figure 7-1 shows the trend in the price of residual oil on the East Coast since 1950, along with the projected increase of 3% a year. With a 1971 cost of \$3.25/bbl the projected cost in 1978 is \$3.88/bbl.

Fuel oil cost for 1978 based on the operating schedule presented in Chapter VI can be calculated as follows:

$$\text{Cost/year} = (\text{Cost/bbl})(\text{bbl/year})$$

$$\text{bbl/year} = (\text{bbl/voyage})(\text{voyages/year})$$

$$\text{bbl/voyage} = \sum_i C_i t_i F$$

Where C_i = Long tons consumed per day at the specified power level

t_i = Days at the specified power level

F = 6.62bbl/Long Ton

Using Figures 4-3 and 4-4 and the operating schedule in Chapter VI, the amount of fuel consumed per voyage can be computed:

$$
\begin{aligned}
\text{Long Tons/voyage} &= (550\text{LT/d})(4.9\text{d}) = 2695 \\
&\ (614\text{LT/d})(5.0\text{d}) = 3070 \\
&\ (614\text{LT/d})(.32\text{d}) = 196 \\
&\ (100\text{LT/d})(.75\text{d}) = 75 \\
&\ (42\text{LT/d})(3.0\text{d}) = 126 \\
&\ \text{Total} = 6162\ \text{LT}
\end{aligned}
$$

$$
\begin{aligned}
\text{bbl/year} &= (6162\text{LT})(26\ \text{voyages/year})(6.62\text{bbl/LT}) \\
&= 1{,}060{,}603
\end{aligned}
$$

$$\text{Fuel Cost in 1978} = (1{,}060{,}603)(3.88) = \$4{,}115{,}139$$

Trend in Cost of Bunker C

FIGURE 7-1

VIII. NUCLEAR FUEL

To understand what affects the cost of nuclear fuel requires an understanding of what the fuel is, and how it is produced.

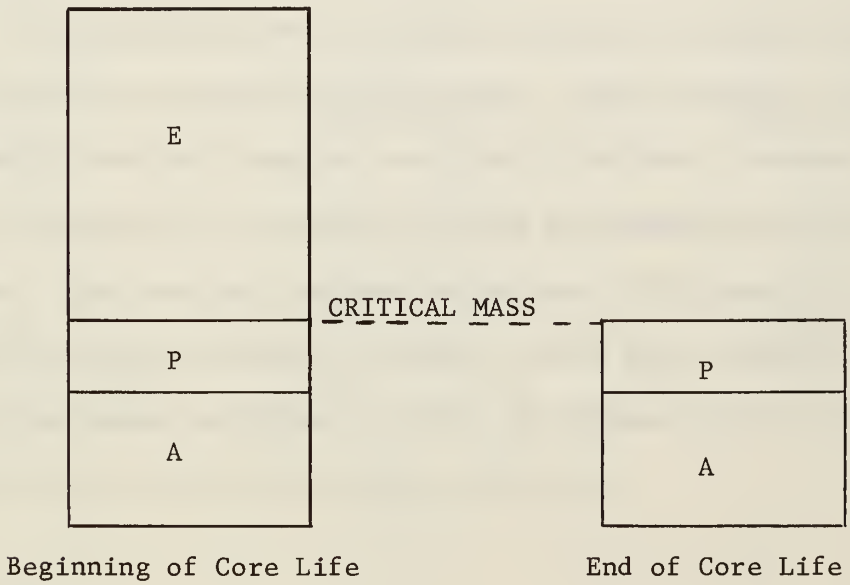
The Core

Energy is generated in the core of a pressurized water reactor when fissile atoms absorb a low energy neutron causing the atom to fission or split apart, on the average, into two different isotopes called fission fragments, plus two or three neutrons. These fission fragments have a high kinetic energy which is converted to heat when they collide with the surrounding fuel and structural material. This is the primary source of heat generated in the core.

The only naturally occurring fissile material suitable for use in the core is an isotope of uranium, U-235, which comprises only .7% of the uranium found in nature. Most of the remaining uranium is U-238 which can be converted to fissile isotopes of plutonium, Pu-239 and Pu-241, by the absorption of neutrons. The breeder reactor is being developed to produce these isotopes in quantities sufficient to meet the increasing demand for fuel. However, they will not be the primary source of fuel until the 1990's.

To sustain the fissioning of the fuel requires that at least one of the neutrons released during a previous fission cause the fissioning of another atom. If this interaction occurs on a continuing basis, a chain reaction is taking place, and the reactor is said to be critical.

To insure that a chain reaction occurs requires that sufficient fissile material be available in the core to have a high enough probability that one of the fission neutrons will be absorbed by the fuel and cause another fission. Otherwise, these neutrons will be absorbed without fissioning by the U-238, structural material, fission products, or water in the core, or they will escape from the core. When U-235 is the fissile material, its concentration is increased by the enrichment of natural uranium to a U-235 content of 2 to 4%. Figure 8-1 area "A" represents the amount of fuel required to achieve criticality in a new core.



Fuel Inventory

FIGURE 8-1

However, as fissioning continues, the fission fragments xenon and samarium, which are very strong neutron absorbers and are known as poisons, build up in the core. Thus additional fissile material must be added above that required for a new core to account for the buildup of these poisons. The total amount of fuel required to keep the reactor critical at anytime during its life is known as the critical mass. Figure 8-1 areas "A" + "P" represents the critical mass of the reactor.

In addition, for the core to operate for a period of time requires an inventory of fuel to be available, otherwise as the fuel is consumed, the amount of fissile material is reduced below the critical mass and a chain reaction can no longer be sustained. This inventory of fuel, Figure 8-1 area "E", is then the material from which the energy is obtained over core life.

As mentioned above, the fissile isotopes Pu-239 and Pu-241 are being produced as U-238 absorbs neutrons. These isotopes then add to the fissile material inventory and life of the core. However, their rate of production is less than the rate of consumption of the fissile material. When the fuel represented by area "E", Figure 8-1 is consumed, the reactor must be refueled. However, there still remains in the core the critical mass consisting of U-235, Pu-239 and Pu-241 which can be separated from the core and sold or recycled.

Fuel Cycle

Figure 8-2 presents the fuel cycle. The quantity of material specified is that amount required at each stage of the manufacturing process necessary to provide the 11,470 Kg of 3.7% enriched uranium required for the core used in this study.

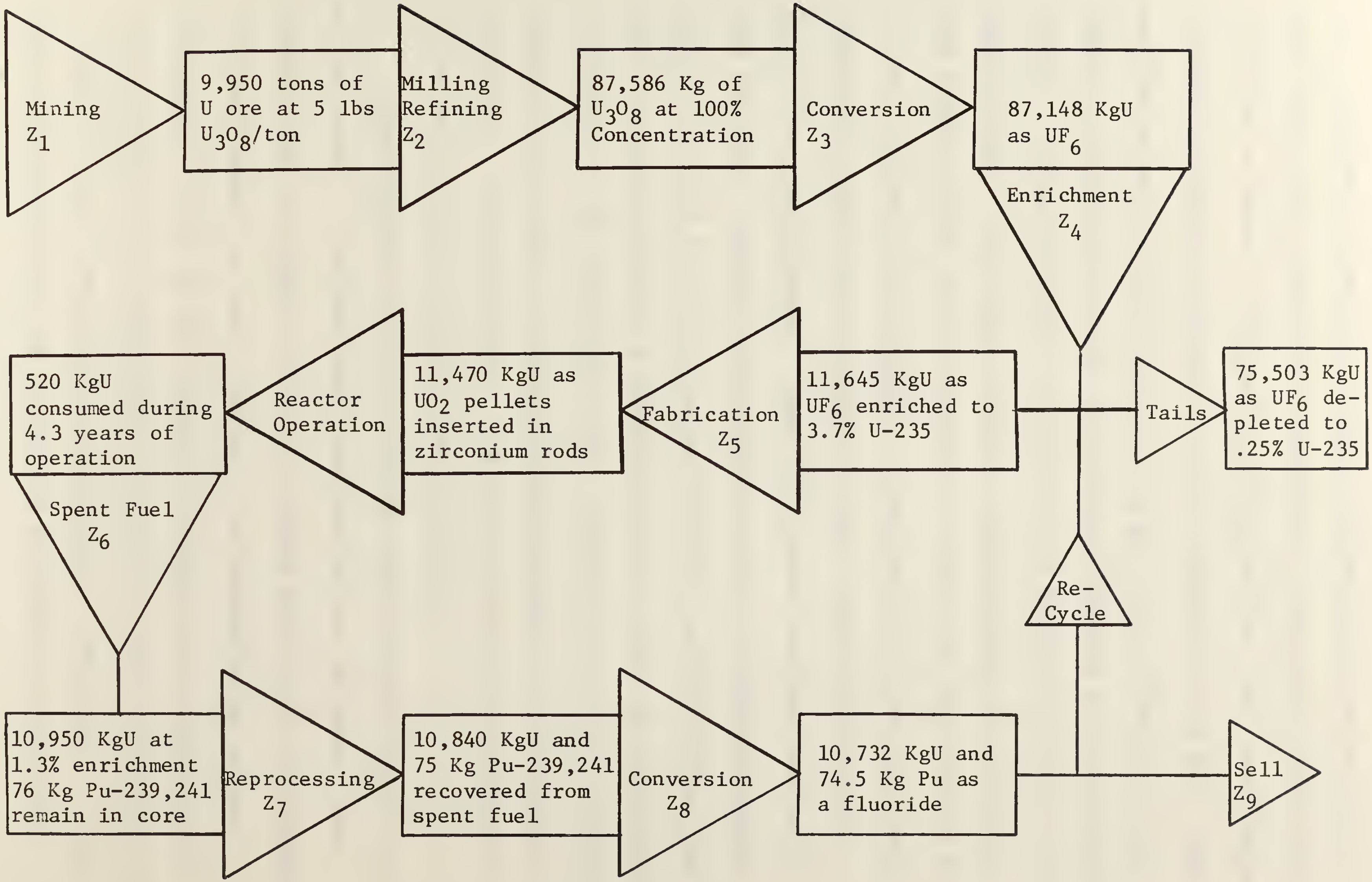


FIGURE 8-2 FUEL CYCLE

Uranium, in the form of U_3O_8, is mined in the western part of this country using conventional techniques. The average concentration of the ore is three to five pounds of U_3O_8 per ton. The concentration is increased during the milling process to between 70% and 90%. This material is known as yellowcake. The U_3O_8 is then refined to a high purity and converted to a gas, UF_6, which is required for the enriching process. During enrichment the percentage of U-235 is increased to the desired level. This process produces a large quantity of depleted uranium known as tails, which is stored for future use. The enriched UF_6 is then converted to the form used in the core, UO_2. The UO_2 is pelletized and loaded into zirconium fuel rods. These fuel rods are grouped into fuel elements. These fuel elements are then combined to form the core. Once the core has been expended, it will be replaced. The old core, due to its high radioactivity and associated decay heat, will be allowed to cool in a storage pool for a number of months prior to shipment to the reprocessing plant. Reprocessing involves the separation of the uranium and plutonium from the spent fuel using chemical techniques. The resulting fuel is a nitrate form which is converted to a fluoride and sold or recycled into a new core.

Cost analysis of nuclear fuel not only involves the direct cost of the process as outlined above, but also the cost of money. This process takes an average of twelve to sixteen months, and the purchaser must make payments at various stages of the manufacturing process. The procurement of fuel can be accomplished through one of several methods. A fuel supplier can be contracted to handle the entire process and supply a finished core, or the purchaser could contract individually for each step of the process from the purchase of yellowcake to final core

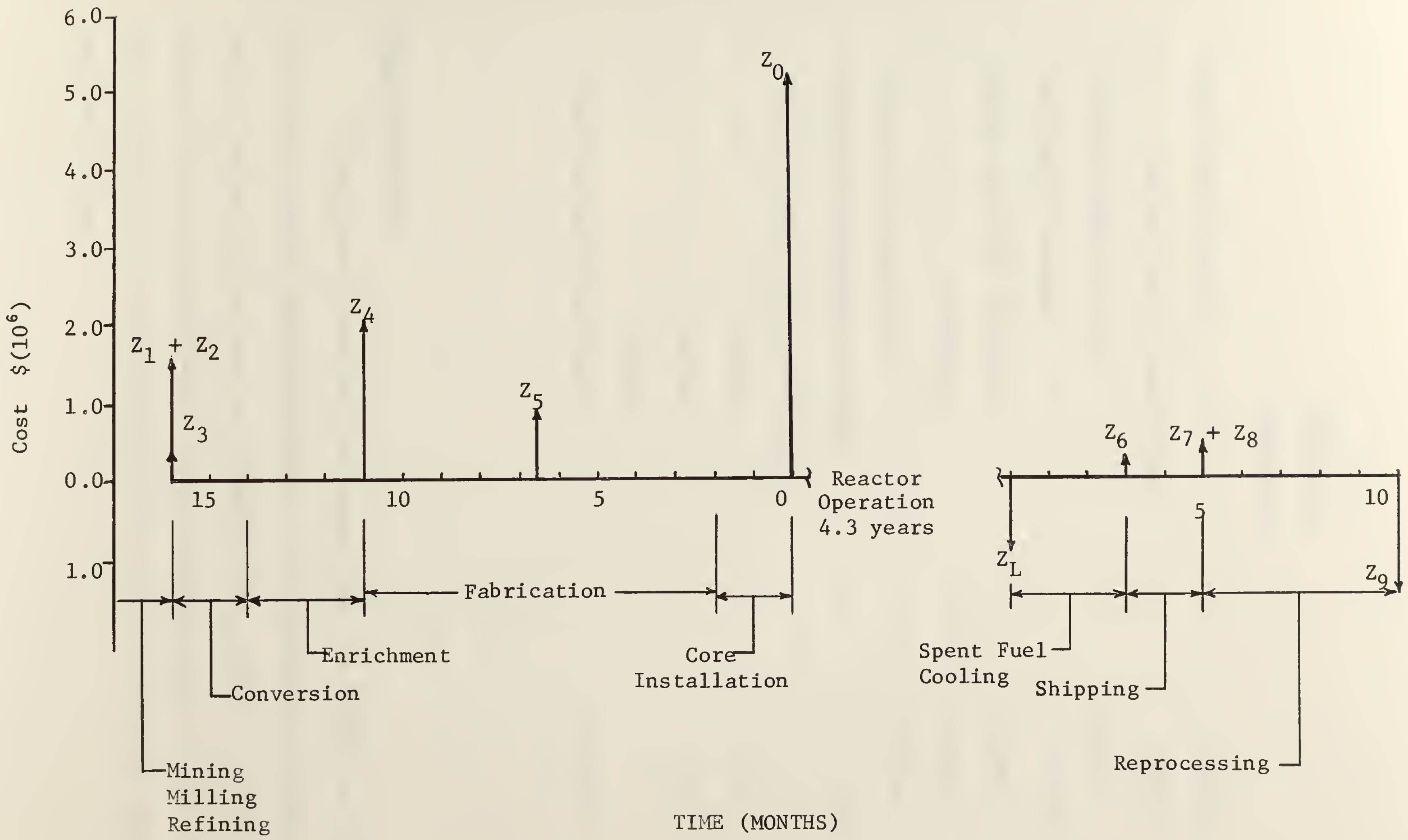
installation. The relative magnitude of the payments and a typical time sequence of when those payments would be made is presented in Figure 8-3. The "Z" designations in Figure 8-3 refer to the particular process specified in Figure 8-2.

To obtain an average annual cost for the core during its operating life, the individual procurement payments during manufacture will be brought, using the present worth technique equation (3-4), to the start up date. Z_0 in Figure 8-3 represents the present worth of all procurement costs.

The ship will then operate from four to five years during which time the inventory charges for owning the fuel and the fuel depreciation must be considered as part of the fuel cost.

At the end of core life, the residual value of the core will be obtained by computing the present worth, at the time the plant is shut down, of all reprocessing costs and subtracting this from the value of the recovered uranium and plutonium. The salvage value of the fuel is represented by Z_L in Figure 8-3. The average annual cost with and without taxes will then be computed using equations (3-11) and (3-12).

The characteristics of the core to be used in this study are presented in Table 8-1.



Fuel Cycle Cost

FIGURE 8-3

Table 8-1

CORE DATA

Power (MWt Nuclear)	312.9
(MWt Nuclear + gamma + pump)	314.1
Initial Loading (Kg U)	11,470
Enrichment (Average)	3.7%
Burnup (MWD/MTU) (Average)	31,000
(Maximum)	45,000
Discharge Loading (Kg U)	10,950
Discharge Enrichment (Average)	1.3%
Discharge Plutonium Pu-239 (Kg)	62
Pu-240	20
Pu-241	14
Pu-242	5
Effective Full Power Days	1,136

Cost Projections

Projections of nuclear fuel costs into the 1980's and beyond are at best educated approximations as are projections of fossil fuel costs. However, projections are necessary for economic analysis of the ship over its operational life. With an understanding of the fuel cycle, nuclear fuel cost projections can now be analyzed by examining each area of cost.

Yellowcake - The Atomic Energy Commission reports that known United States uranium reserves in 1971 that were available at less than $10 per pound, were 390,000 tons with 246,000 tons of this ore available at less than $8 per pound, and estimated additional reserves of 680,000 tons[18]. With the cumulative demand by 1980 expected to be about 200,000 tons, the known United States reserves are sufficient to last into the 1980's and the estimated reserves well into the 1990's. When breeder reactor development is considered, the actual demand for uranium peaks in the 1990's as plutonium becomes available in significant quantities. This peak will occur earlier if the plutonium now being produced in light water reactors is recycled. By 1980, the annual plutonium production is estimated to be 25,000 Kg[17]. In addition, the United States Government stockpile of 50,000 tons and the option to import uranium if required, insure the availability of this fuel well into the next century.

As a result of the present over supply of uranium, the yellowcake price is somewhat depressed, and is expected to remain so through the middle of the 1970's, after which time it will follow the cost of production. The 1976 cost of yellowcake is estimated to be $7 per pound.

The cost of production can be broken down into labor cost, material cost, and fixed cost. Table 8-2 shows this breakdown along with the escalation rate based on a labor escalation rate of 6% per year and material at 3% per year and the 1976 estimated cost.

Table 8-2

BREAKDOWN OF FUEL CYCLE COST

Item	Labor %	Material %	Fixed %	Escalation %/Yr	Cost 1976
Mining, Milling Refining U_3O_8	40-45	40-45	10-20	3.6	7.00
Conversion U_3O_8 to UF_6	30	60	10	3.9	3.00
Enrichment	15	50	35	3.4	34.00
Fabrication	60	30	10	-2.0 (to 1982)	78.40
Reprocessing	15	18	67	-1.0	31.00
Shipping	40	30	30	3.3	6.00

Conversion - The conversion of U_3O_8 to UF_6 is performed in commercial plants using a chemical process. Its cost is expected to increase along with the general cost trend. The cost in 1976 is estimated to be $3.00 per Kg U.

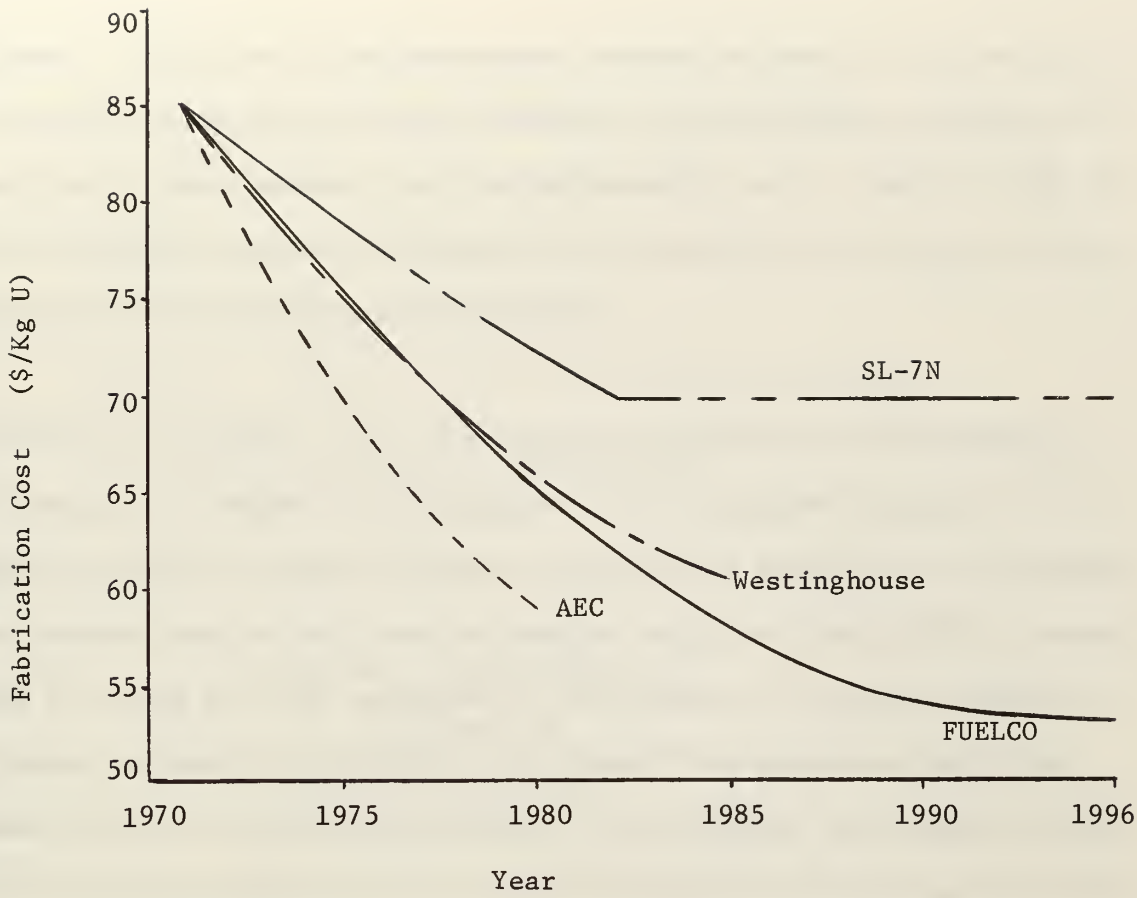
Enrichment - Presently the Federal Government is the only supplier of enriched uranium. However, the Atomic Energy Commission has recently initiated procedures to make available to certain manufacturers technical information on the enrichment process so that they could evaluate the feasibility of establishing commercial enrichment facilities.

Enrichment costs are established by the government based on the estimated cost of production over a given time frame. The price for enrichment is then set at a flat rate over this time period. The

rate established in 1971 of $32 per separative work unit per Kg U is supposed to exist through the middle of the 1970's. However, to be conservative, the 1976 price is assumed to be $34 and to escalate from that point based on the breakdown of cost as shown in Table 8-2.

Fabrication - The cost of fabrication is subject to the normal escalation with a cost breakdown as shown in Table 8-2. However, the cost of fabrication is also subject to cost reductions due to volume, automation and learning curve type of improvements. Projections by Westinghouse Electric Corporation show an average annual reduction in cost of about 2.6% per year through 1985[19]. The Atomic Energy Commission shows a reduction of about 3%/year through 1980[20]. Oak Ridge National Laboratory developed a detailed computer program known as FUELCO to provide estimates of fuel cost as a function of time. These projections show a 1% to 2% decrease in the cost of fabrication through the year 2000[21].

The cost of fabrication for a large utility in 1972 was averaging from $70 to $85 per KgU. With a three ship purchase, the cost of fabrication is assumed equal to that of a utility company, and the $85 per Kg U cost is assumed for 1972. Figure 8-4 plots the projected cost using the three estimates discussed above. To be conservative, a 2% reduction in the cost of fabrication will be assumed through 1982, thereafter the price is assumed to remain constant. The 1976 cost is $78.40 per Kg U.



Trend in Fabrication Cost

FIGURE 8-4

Reprocessing - The recover of fuel from the spent core is also volume dependent. The rapid growth in nuclear power plants indicate the need for large reprocessing facilities. There are several high capacity plants either planned or under construction. Therefore, the cost of reprocessing is expected to decrease through the 1990's. Estimates of cost reduction average from 1.5% to 2% per year. A 1% reduction is assumed for this study.

Shipping - The cost of shipping is related directly to the breakdown given in Table 8-2.

Uranium - The value of the reprocessed uranium is equal to the value of an equivalent amount of uranium enriched to the discharge enrichment at the time of reprocessing, less the reprocessing cost. Thus the value of the discharged uranium is affected by the current price of U_3O_8 and the current cost of conversion and enrichment.

Plutonium - The value of the discharged plutonium can be determined by its value as a competitive alternative fuel to enriched uranium or as a fuel for breeder reactors. However, substantial quantities of plutonium for breeder reactors will not be required until the late 1980's at which time its value has been estimated to be between two and three times as valuable as when it is recycled. To retain this plutonium until the demand arose is not practical because of the storage and inventory cost. An alternative would then be to recycle the plutonium from the first two cores, then to sell the plutonium as a breeder fuel when the remaining cores are reprocessed after 1991.

The value of the recycled plutonium is obtained by determining what amount of equivalent uranium it represents and deducting any additional costs. As indicated above, reprocessing is a volume dependent operation. With the relatively small cores of the SL-7N, the value of the plutonium is reduced substantially because of this increased cost. To alleviate this situation, the plutonium could be sold to a utility, which has a high volume throughput, at a higher price than its value to the SL-7N when recycled.

The value when recycled for the SL-7N is obtained as follows: It is assumed that the plutonium will be blended with the tails remaining from the enrichment process.

EP = Enrichment of discharged plutonium

AP = Amount of discharged plutonium

ET = Enrichment of tails

AT = Amount of tails

DE = Desired enrichment

AT + AP = Amount of fuel at the desired enrichment

$$(EP)(AP) + (ET)(AT) = DE(AT + AP)$$

For the SL-7N this would then be:

$$76 + (.0025)AT = (.037)(AT + 101)$$

$$AT = 1995 \text{ Kg}$$

$$AT + AP = 2096 \text{ Kg}$$

However, because the nuclear properties of plutonium are somewhat lower than uranium for use in light water reactors, the equivalent amount of enriched uranium equal to 2096 Kg of plutonium fuel is only .9(2096) or 1886 Kg. The value of this enriched fuel will then be obtained by using the current price of uranium and the current cost of conversion and enrichment at the time of reprocessing.

In addition to the reduction in value due to its nuclear properties, plutonium is also more expensive to fabricate due to its toxicity and the requirement for stricter controls and remote handling. This increased fabrication cost must be subtracted from the value of the recycled plutonium. This increase in cost has been estimated to range from between 15% and 60% by the government and industry. By 1982, the time that the first core will be reprocessed, plutonium recycle facilities will be firmly established and the increase in price will

have been substantially reduced. A conservative estimate of a 25% increase in the cost for fabricating plutonium is assumed.

Using the above assumptions, the value of recycled plutonium at 1972 prices for the SL-7N would be $4.11 per gram.

There have been several purchases of plutonium in 1972 at $7 per gram. This increase in the value of plutonium over that for the SL-7N reflects the effects of volume throughput.

For this study a conservative middle of the road approach will be used. It will not be assumed that the plutonium can be sold at a higher value as a breeder fuel, neither will it be assumed that the plutonium will be recycled for use in the SL-7N at its low value. Instead it is assumed that the plutonium will be sold at 1972 prices to a utility for recycle at $6 per gram, $1 per gram less than its known value in 1972. This value will increase with time as the value of uranium as discussed above.

With the economic data from Table 3-1, the core data from Table 8-1, and the cost of each fuel processing step with its associated escalation from Table 8-2, the core cost can be computed. Based on the operating schedule presented in Chapter VI, the core will operate for 4.32 years. Table 8-3 shows the results of a computer cost analysis using the program presented in Appendix B for the first core of the SL-7N.

Refueling

Appendix C shows a 28-day refueling schedule which assumes worker familiarity with the equipment and procedures. No major breakdowns in equipment are allowed, however, there is sufficient slack to

Table 8-3

CORE I SL-7N

Item	Time of Payment	Payment
Purchase U_3O_8	4/76	1,594,042
Conversion U_3O_8 to UF_6	4/76	263,322
Enrichment	9/76	2,068,169
Fabrication	1/77	912,942
Total Direct Cost		4,838,475
Present Worth of Cost At the Start of Operations		5,111,190
Refuel	4/82	
Ship Spent Fuel	7/82	77,280
Reprocessing	9/82	322,814
Value of Recovered Uranium	2/83	967,482
Value of Recovered Plutonium	2/83	601,873
Direct Salvage Value		1,169,261
Present Worth of Salvaged Fuel at Shutdown		1,107,998
Net Present Worth at the Start of Operations		4,235,330
Average Annual Cost Over The Life of the Core		1,129,937

account for inevitable delays. This schedule should be achievable by the fourth refueling. With three ships then, the second and subsequent refuelings on each ship are assumed to follow this schedule. Although shorter schedules have been proposed in similar studies, and several utility company refuelings have been accomplished in a shorter time period, the twenty-eight day schedule is believed to be realistic and will be used in this study. The first refueling for each ship is assumed to take 1-1/2 times as long, or forty-two days to allow the workers time to become familiar with the equipment and procedures, and to correct any errors in procedure. This time span is in agreement with the time required for the partial refueling and the defueling of the N.S. SAVANNAH.

Refueling Cost

The cost of refueling will be broken down as follows:

Refueling Facility - The cost of those facilities at the shipyard assigned to refueling such as the transfer cask, storage pool, radiological control equipment, etc. Refueling facility cost will be based on the 1967 cost of the Galveston facility of $800 per day[8]. The estimated cost in 1978 is $1,108 per day and in 1982, $1,246 per day.

Refueling Labor - The refueling crew will consist of three shifts per day and will work seven days per week. Each shift crew will be composed of approximately nineteen men. It is estimated that the entire crew will be required two-thirds of the time or twenty-eight days for the first refueling. For the remaining fourteen days, nine men per shift will be required. Based on an average hourly cost for shipyard workers in 1971 of $10 per hour, the 1978 and 1982 costs are

respectively $15 and $18.98 per hour.

Ship Force - Seventeen members of the ship's engineering department will be required to operate the plant and to witness shipyard work. In addition, four members of the deck crew will be required for ship security. Based on the 1971 average cost per day of $70 per man, the cost per man in 1978 would be $105.25 per day and in 1982, $132.88 per day.

Miscellaneous Expenses - Those expenses not covered under the other categories. Included here is the cost of protective clothing laundering services, film badge service, expendable materials, and waste disposal. The 1967 cost for a sixty-man force for twenty-eight days was $17,310. The 1978 daily cost would be $713.14 and the 1982 cost, $802.64.

All refueling costs are escalated at a rate of 6% per year for labor and 3% per year for material.

For this study refueling costs are considered an operating expense for the year of refueling. Other studies have included this cost as part of the nuclear fuel cost and averaged it over the life of the core. This is not the practice of utilities and will not be used here.

Table 8-4 presents a summary of the refueling cost for the first refueling of forty-two days in 1982.

Table 8-4

REFUELING COST

Refueling Facility (42 days)	52,332
Refueling Labor	299,732
Ship Force	117,200
Miscellaneous	31,795
Total	501,059

IX. REVENUE

Revenues derived from carrying cargo depends on the cargo utilization, that is the quantity carried, and the freight rate.

The cargo utilization factor is the fraction of the ship's available cargo carrying capacity that is filled with revenue producing cargo. For the North Atlantic trade this factor is over 90%. The cargo carrying capacity of the SL-7 and SL-7N as noted in Chapter IV consisted of 1,096 containers plus general cargo in holds 1 and 2.

The freight rates depend on many variables which include the particular trade route, the value of the cargo, the type of cargo, the weight and volume of the cargo, and the amount of competition on the trade route. In 1972, the cost of shipping a container from New York to Rotterdam or Bremerhaven was anywhere from \$800 to \$2,200. An average cost of \$1,200 per container will be used in this study with a 3% escalation.

It will be assumed that the total revenue per crossing in 1972 will be equal to

$$(2)(\$1200)(1096) = \$2,630,400$$

This assumes that the cargo utilization will be less than 100% by the amount of cargo space available in holds 1 and 2. The total revenue per voyage in 1978 is then \$3,140,970.

X. ECONOMIC ANALYSIS

Now that the criteria and basic assumptions have been formulated, an economic analysis can be performed. To aid in this analysis, a computer program has been written and is presented in Appendix B.

The analysis will be accomplished by assuming an expected trend in expenses over the ship's life, and then performing a sensitivity analysis about the basic program with some of the more important parameters. The basic criteria used in this comparison will be the average annual cost (AAC). The assumptions for the basic program are those presented in Tables 3-1, 5-1, 5-3, 5-4, 6-3, 6-4, 8-1, 8-2, 8-4 and Chapter IX. The assumptions are believed to be conservative and in general to favor the fossil fueled ship. That is, for example, the cost of fossil fuel is expected to increase at a faster rate than the 3% assumed for the basic program, and the cost of nuclear fuel is expected to escalate at a somewhat slower rate than assumed.

In addition, the average annual net profit (AANP) will be examined. Although this requires additional assumptions, which tend to make the comparison somewhat more speculative, it is necessary to examine what effect the loss of revenue, during the refuelings of the SL-7N, has on the net profit of the ship.

Basic Program

The results of the comparison of the average annual cost (AAC) and the average annual net profit (AANP) using the data presented in

the previous chapters along with their assumed rate of escalation is presented below:

Average Annual Cost SL-7	=	28,861,455
Average Annual Cost SL-7N	=	28,731,920
Average Annual Net Profit SL-7	=	30,845,480
Average Annual Net Profit SL-7N	=	30,759,100

The average annual cost of the SL-7N is shown to be slightly less than that for the SL-7. However, the average annual net profit of the SL-7 is slightly larger due to the loss of revenue during the four refuelings of the SL-7N.

Based on the validity of the assumptions, it is concluded that the two ships are competitive and that the difference in the results is too small for use as a means of selecting either alternative. Further analysis is thus required.

Zero Escalation

The results of a comparison in which it was assumed that there was no escalation of costs or revenue over the ship's life are as follows:

Average Annual Cost SL-7	=	23,211,945
Average Annual Cost SL-7N	=	23,986,650
Average Annual Net Profit SL-7	=	23,572,190
Average Annual Net Profit SL-7N	=	23,261,100

The advantage held by the SL-7N of a lower average annual cost of about $130,000 using the basic program has now shifted to a $770,000 disadvantage. The reason being that in the basic program, fossil fuel

cost escalated at a faster rate than nuclear fuel cost, whereas the escalation is now assumed to be zero. The major economic advantage of the nuclear powered ship has thus been eliminated.

The average annual net profit has also grown in favor of the SL-7, however at not as fast a rate as the average annual cost. This is because the effect of lost revenue during refueling has been reduced with zero escalation in revenue.

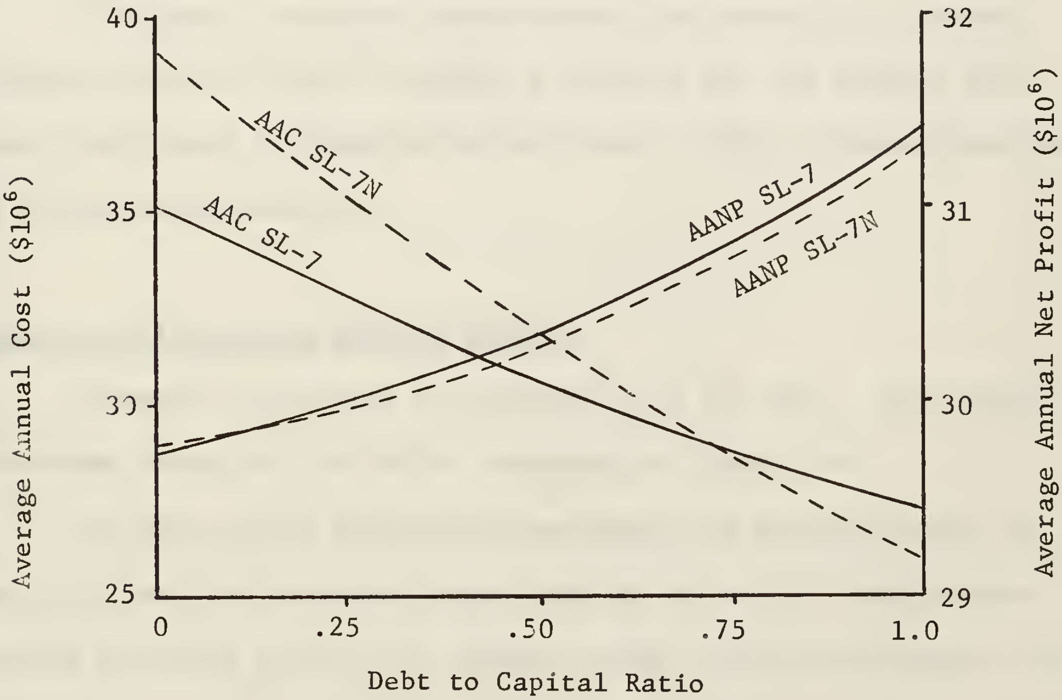
The conclusion based on the assumption of zero escalation would then be that the SL-7 is more economical, although by only 3.23% of the average annual cost and 1.3% of the average annual net profit. The assumption of zero escalation is obviously invalid, however, the results do provide a benchmark for future comparison.

Varying the Debt to Total Capital Ratio

The assumed debt to total capital ratio, b, of .75 will now be varied from 0.0 to 1.0.

Figure 10-1 shows that the average annual cost of the SL-7N decreases below that of the SL-7 at debt to capital ratios above about .74. This was to be expected due to the higher capital cost of the SL-7N. As the debt to capital ratio increases, the effective cost of money, given by equations (3-9), decreases due to the tax credits on interest payments that are tax deductible. In addition, the debt interest rate assumed was lower than the equity return rate, therefore, at higher debt to capital ratios the lower interest rate reduces the effective cost of money. It thus appears that choosing a high debt to capital ratio favors the nuclear ship. However, this is not necessarily true. Looking at the effect on the average annual net profit, the

opposite result is obtained. That is, as b decreases, the average annual net profit of the SL-7N increases above that of the SL-7 at b less than about .1. It must be remembered that the average annual net profit and the average annual cost are not only looking at the direct cost, but also the time value of money. The present value of receiving $1 a year from now at an effective cost of money of 4% is $.96, whereas its present value at an effective cost of money of 8% is only $.92. Thus, the higher the effective cost of money, the lower will be the value today of an income or expenditure a year from now.



Variation of the

Debt to Total Capital Ratio

FIGURE 10-1

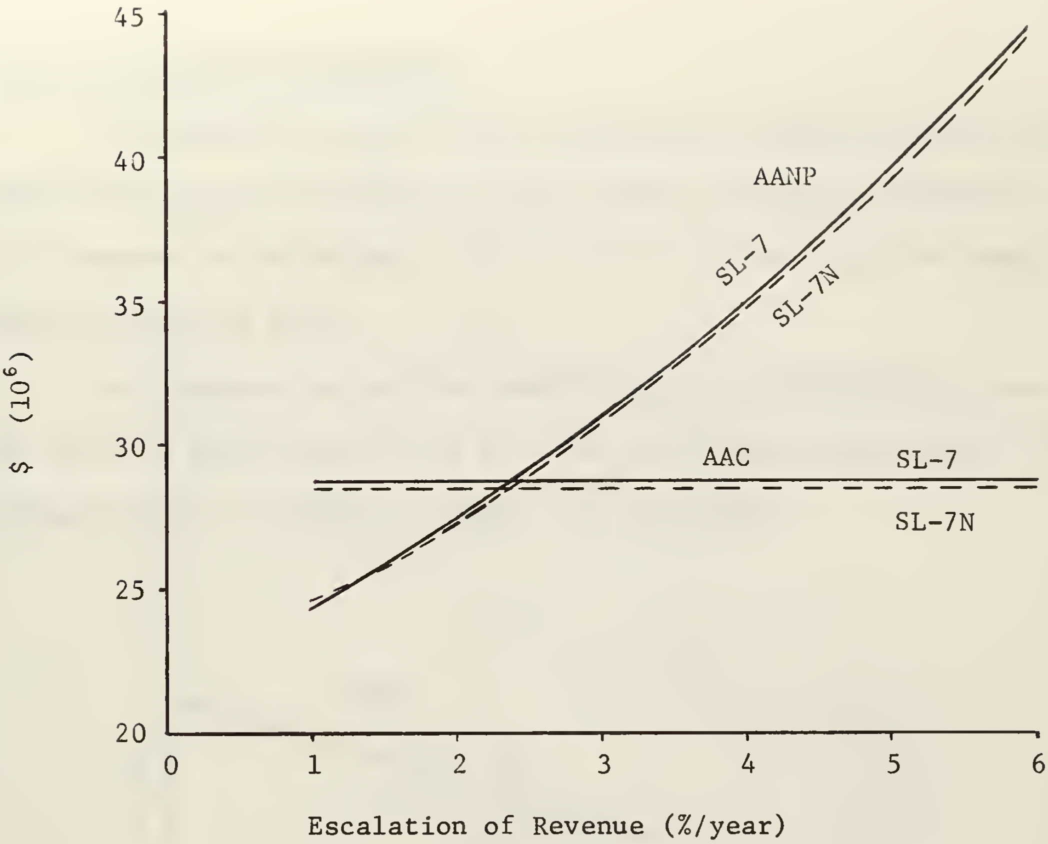
This effect is clearly seen with the average annual net profit. Here not only the effect of cost is being examined, but also the effect of revenue. As b decreases, the effective cost of money increases, thus the present value of the loss of revenue due to refueling in the fifth, ninth, fourteenth, and eighteenth years of operation is reduced. At a debt to total capital ratio of .1, the reduction in the effect of the lost revenue during refueling overrides the increase in cost due to higher interest payments and the average annual net profit of the SL-7N becomes larger than that of the SL-7. Of course, with a choice of different parameters, this crossover may not occur or occur at a higher b.

The above discussion demonstrates the necessity of examing different criteria prior to making a decision for the results that might intuitively be expected may not occur. This is demonstrated again in the following analysis.

Varying the Escalation Rate of Revenue

Revenue was assumed to escalate at 3% per year. The effect of escalation rates of 1% to 6% is presented in Figure 10-2.

As the rate of escalation decreases, the average annual net profit of the SL-7 decreases below that of the SL-7N. This occurs because the value of the lost revenue during refueling decreases with a decreasing rate of escalation. Therefore, the effect of the lost revenue decreases and the difference between the average annual net profit of the SL-7 and SL-7N decreases until about a rate of escalation of 1.4% below which the SL-7N becomes more profitable.



Variation of the

Escalation Rate of Revenue

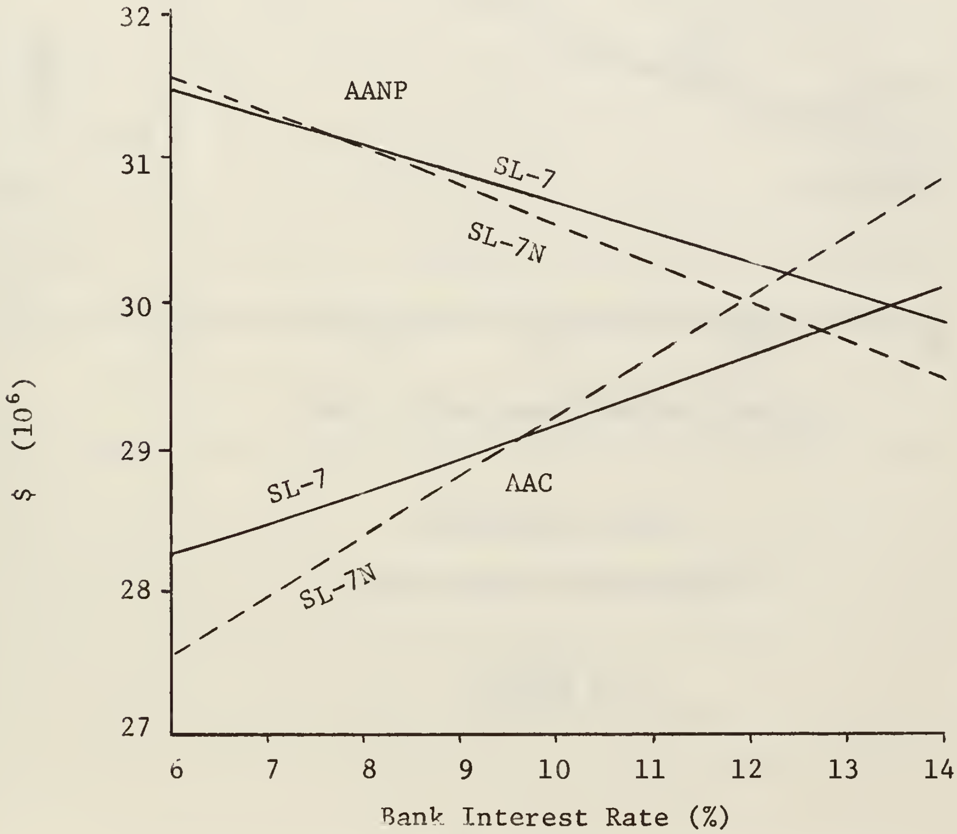
FIGURE 10-2

This analysis points out the importance of minimizing the loss of revenue. It must be remembered that the SL-7 was assumed to have only a one week outage every five years. If, in fact, an outage time of two or three weeks is more likely, then the effect of lost revenue during refueling will be reduced and the point at which the SL-7N becomes more profitable will occur at a higher escalation rate.

Varying the Bank Interest Rate

The assumed interest rate of 9% will be varied from 6% to 14%. Figure 10-3 shows that higher interest rates are more detrimental to the SL-7N because of the higher capital cost of the ship and the capital nature of nuclear fuel.

At interest rates below about 9.6%, the average annual cost of the SL-7N is below that of the SL-7 and at interest rates below 7.6% the average annual net profit is higher for the SL-7N.



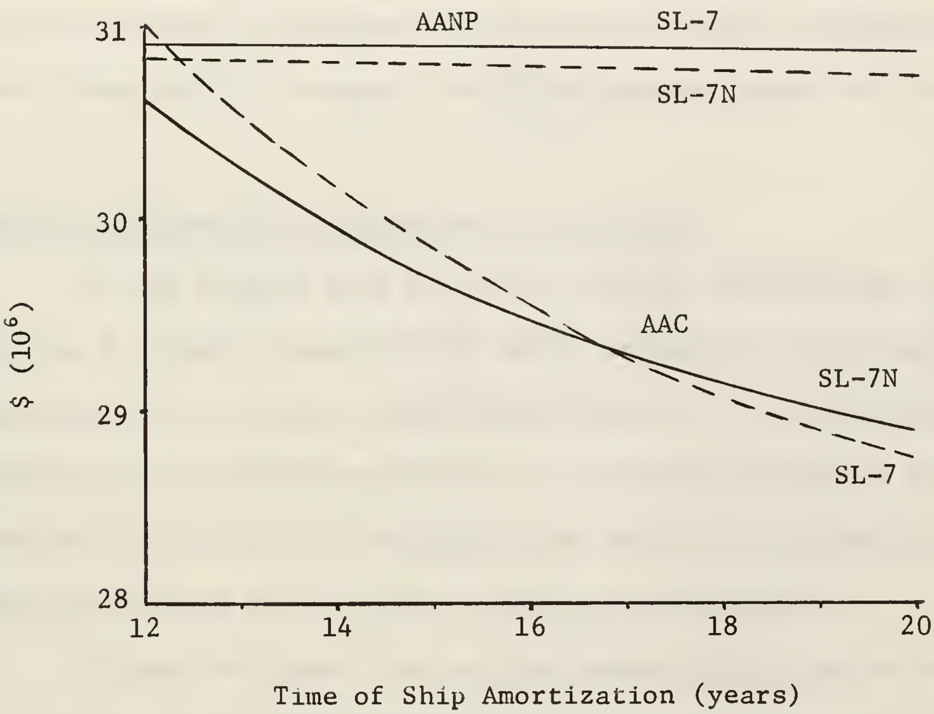
Variation of the

Bank Interest Rate

FIGURE 10-3

Varying the Amortization Period

The amortization period of twenty years assumed for the basic program will be varied from twelve to twenty years.



Variation of the

Time of Ship Amortization

FIGURE 10-4

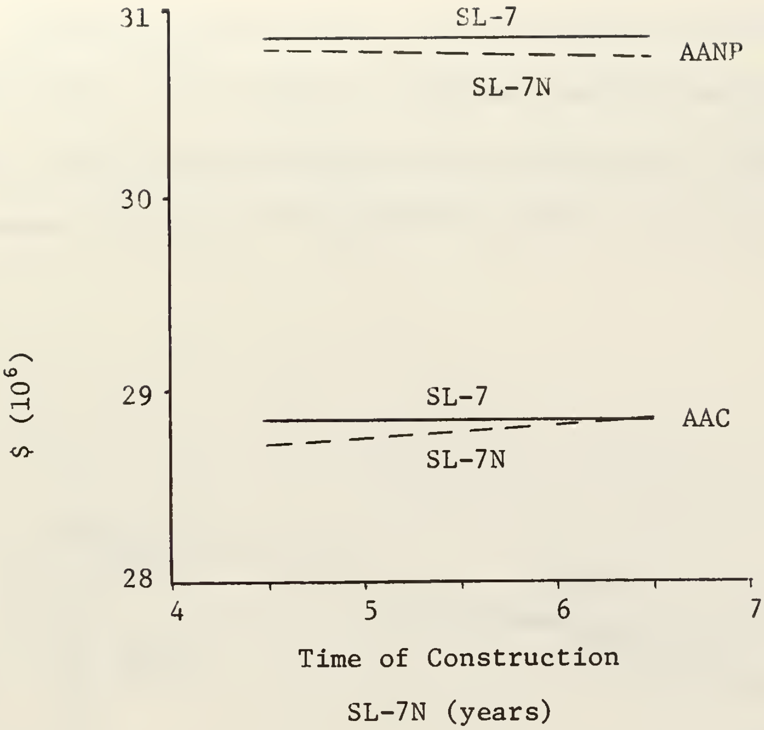
Figure 10-4 shows that as the amortization period is extended beyond seventeen years, the average annual cost of the SL-7N decreases below that of the SL-7. However, as with Figure 10-1, what might have intuitively been expected to happen with the average annual net profit, is different from the results. Here again, the time value of money

shows its effect. For as the amortization period decreases, the time at which the annual net profit of the SL-7N increases above that of the SL-7 is reduced, thus the sum of the present value of the annual net profit and the average annual net profit of the SL-7N increases at a faster rate than that for the SL-7. Although this rate of increase is not great enough to overcome the higher amortization payments of the SL-7N, thus the SL-7 retains the higher average annual net profit.

Varying the Time for Construction of the SL-7N

It was assumed that the total time for construction of the SL-7N would be 4.5 years, based on the vendor estimate of fifty months for completion of the nuclear steam supply system. This time could be extended due to construction delays or licensing problems as being encountered by utilities. Therefore, the effect of lengthening the construction time to 5.5 or 6.5 years will be examined.

Figure 10-5 shows that as the construction time for the SL-7N is increased, the average annual cost increases, and at about 6.4 years equals that of the SL-7. The average annual net profit of the SL-7N decreases with increasing construction time, the difference between the SL-7 and SL-7N increasing. However, the average annual cost and the average annual net profit are not as sensitive to variation in construction time as are most of the other parameters being examined.



Variation of the

Time of Construction

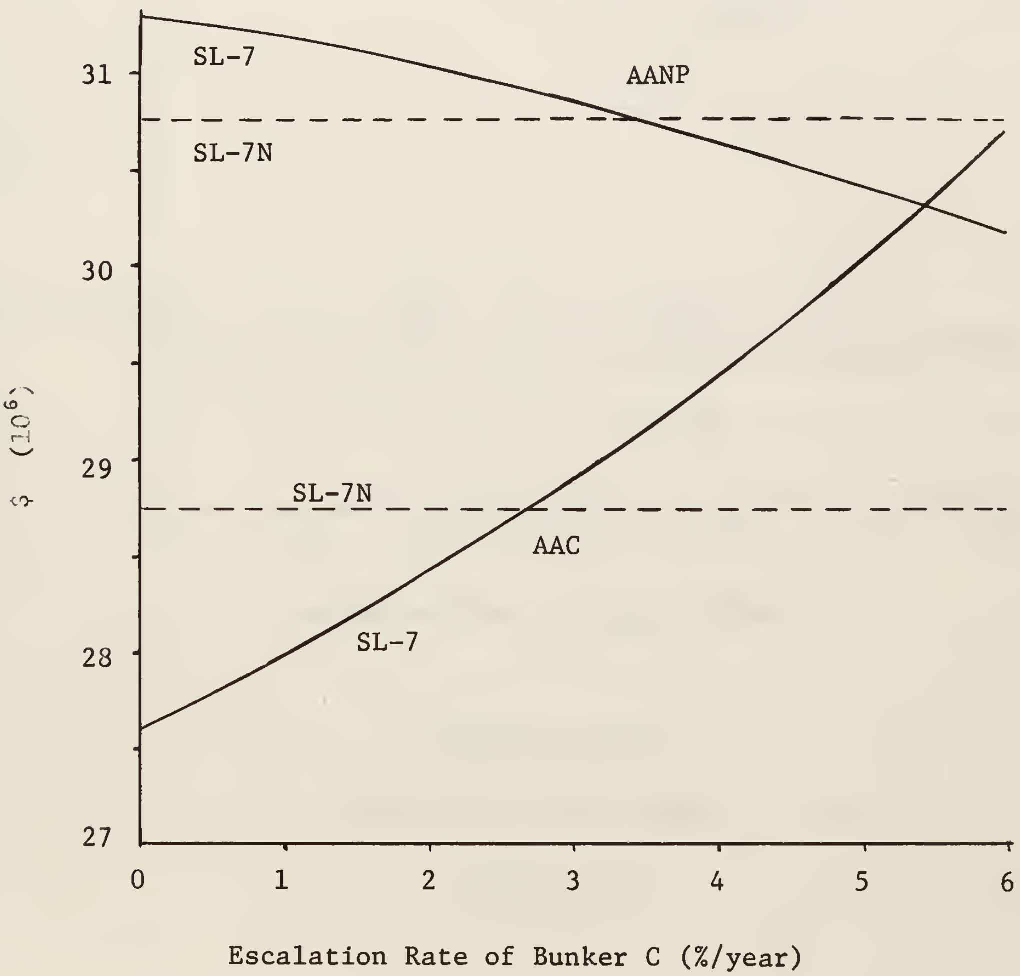
of the SL-7N

FIGURE 10-5

Varying the Escalation Rate of Bunker C

Fuel oil was conservatively estimated to increase at 3% per year based on known contracts that exist with Middle East countries and the requirement to increase exploration to meet demands at home. The actual rate of escalation could be higher than the assumed rate if the oil companies decide to pass along all of the increases in cost that result from the Middle East agreements, or if the OPEC countries gain the participation they desire and force up the price of crude oil.

Figure 10-6 shows that at an escalation rate above 2.8% the average annual cost of the SL-7 becomes greater than that of the SL-7N. However, the rate of escalation must be larger than 3.5% before the average annual net profit increases above that of the SL-7.



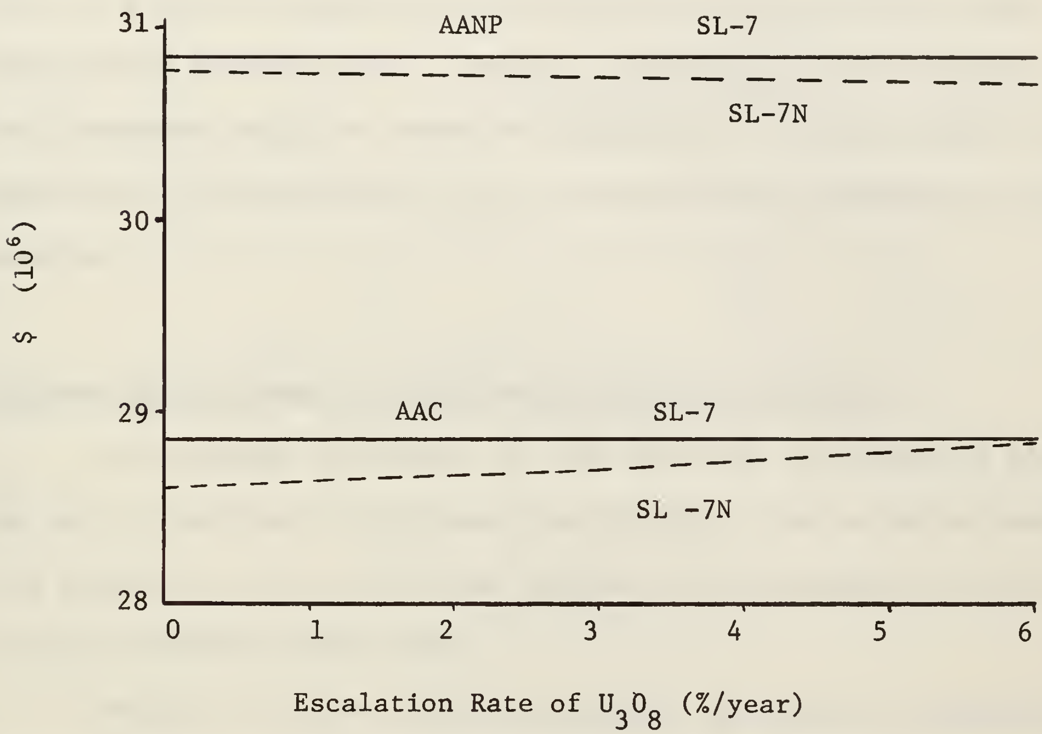
Variation of The

Escalation Rate of Bunker C

FIGURE 10-6

Varying the Escalation Rate of the Cost of Uranium

The effect of escalation on the cost of yellowcake different from the 3.6% selected for the basic program will now be examined.



Variation of the

Escalation Rate of U_3O_8

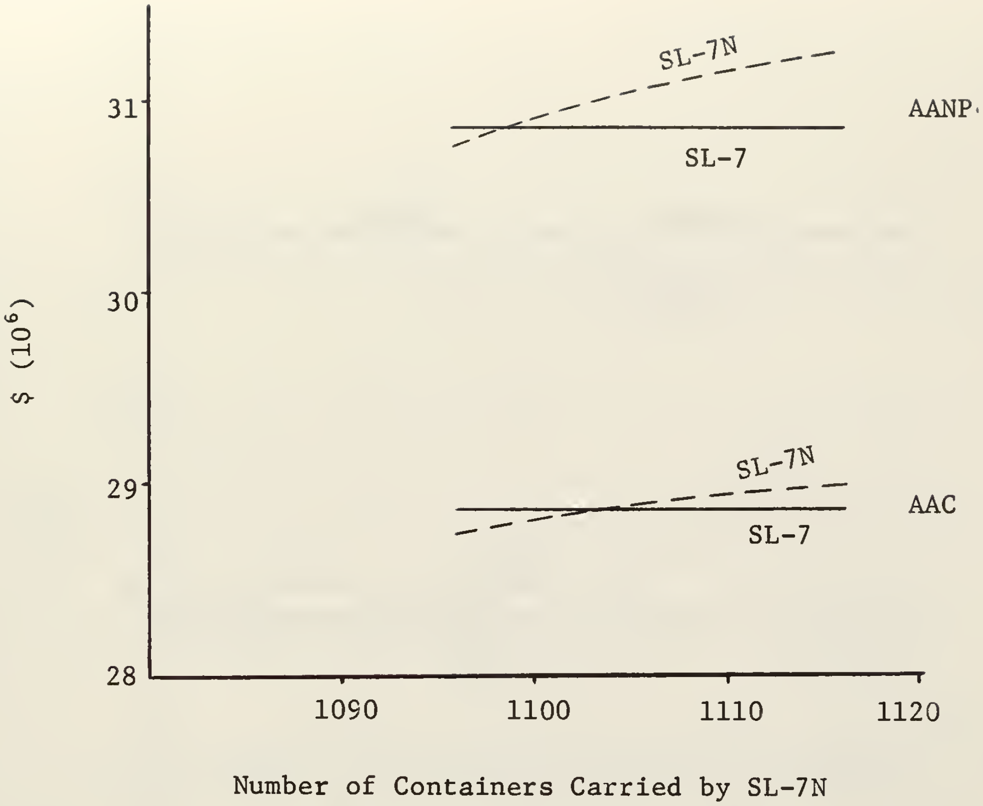
FIGURE 10-7

Figure 10-7 shows that a variation in the escalation rate for yellowcake has a relatively minor influence on the average annual cost and the average annual net profit. Because the cost of yellowcake is one of the three major expenses in the cost of nuclear fuel, the other two being the cost of enrichment and the cost of fabrication, it can be asserted that a variation of one or two percent of any particular fuel cycle cost will not significantly effect the final decision in the selection of a power plant. However, a variation of all fuel cycle cost parameters would of course be significant. A large number of combinations in the variations of the fuel cycle cost parameters is thus possible.

Increase in the Number of Containers Carried by the SL-7N

As discussed in Chapter IV, the SL-7N may be capable of carrying ten to twenty more containers than the SL-7, due to the elimination of a portion of the aft house and uptakes and the reduction in the fuel oil plus lightship displacement.

Figure 10-8 shows that by increasing the number of containers carried by three, the average annual revenue of the SL-7N increases above that of the SL-7 overcoming the effect of lost revenue during refueling. The average annual cost of the SL-7N increases due to the increase in the total cargo handling expense with the increased number of containers.

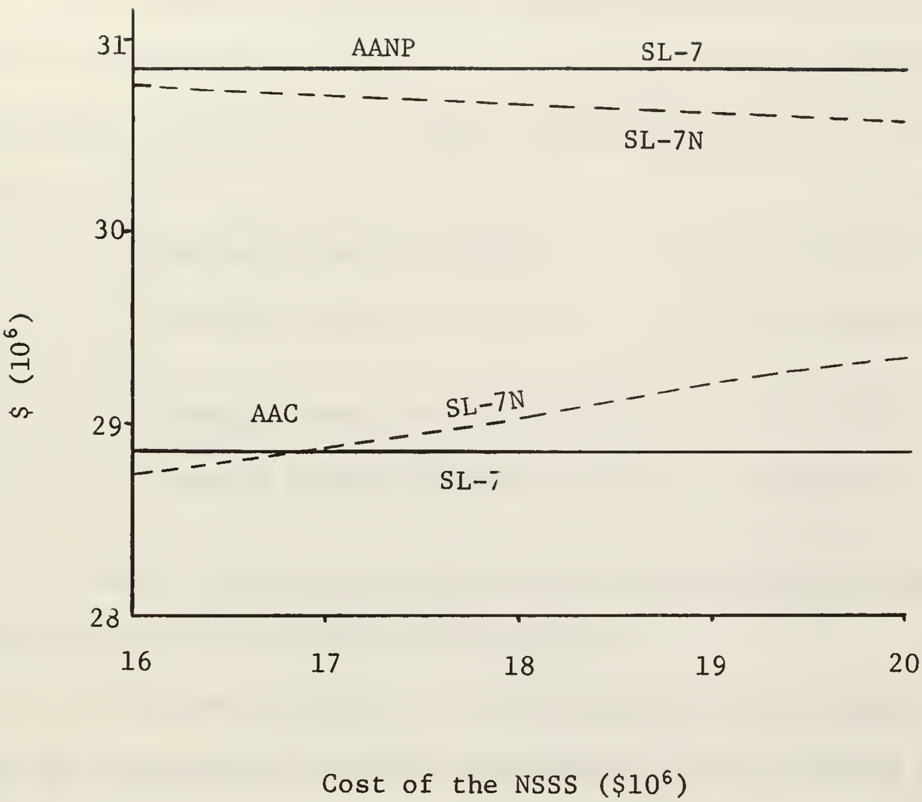


Variation of the Number
Of Containers Carried
By the SL-7N

FIGURE 10-8

Varying the Construction Cost of the SL-7N

If the difference in the construction cost of the two ships were to increase, the probable cause would be an increase in the cost of the nuclear steam supply system. As shown in Figure 10-9, with the vendor estimated cost for the NSSS of $16,000,000 the SL-7N is competitive, however, with cost in excess of $17,000,000 the SL-7 becomes the clear choice assuming the other assumptions are correct.



Variation of the
Cost of the NSSS

FIGURE 10-9

Selection of alternative power plants depends on many factors which if combined in the proper manner, can be made to favor either side. For example, by assuming an interest rate of 7.5%, an escalation rate of fossil fuel of 5%, and the SL-7N carrying the additional twenty containers, the results are clearly favorable for the SL-7N as shown below:

Average Annual Cost SL-7	=	29,672,748
Average Annual Cost SL-7N	=	28,163,900
Average Annual Net Profit SL-7	=	31,455,280
Average Annual Net Profit SL-7N	=	31,875,710

Careful selection of criteria is thus of primary importance in the selection of alternative power plants.

As stated in Chapter I, the objective of this study is to compare the economics of a nuclear powered and a fossil fueled containership in a manner that has a minimum of assumptions. So far, this study has assumed no government support of any kind other than third party nuclear liability. However, the comparison would be incomplete without observing the effect of a construction differential subsidy. As discussed in Appendix A, the Merchant Marine Act of 1970 reduces the construction differential subsidy from the previously available 55% to 35% in 1976. Although this subsidy would not be available to unsubsidized operators such as Sea-Land Service, it would be available to the numerous subsidized operators such as American Export Isbrandtsen Lines, and therefore must be considered.

Applying a 35% construction differential subsidy to the basic program for both ships results in the following:

Average Annual Cost SL-7	=	25,955,419
Average Annual Cost SL-7N	=	24,932,060
Average Annual Net Profit SL-7	=	31,562,800
Average Annual Net Profit SL-7N	=	31,696,540

The SL-7N would then be the clear choice with an average annual cost of $1,023,000 less than the SL-7 and an average annual net profit larger by $134,000.

Furthermore, applying the subsidy in the case of zero escalation of cost and revenue:

Average Annual Cost SL-7	=	20,305,908
Average Annual Cost SL-7N	=	20,186,700
Average Annual Net Profit SL-7	=	24,289,500
Average Annual Net Profit SL-7N	=	24,198,540

Thus with the subsidy the SL-7N is competitive in the case of zero escalation, whereas it was clearly the loser without the subsidy.

XI. SUMMARY

The judgment of risk versus potential return on investment for any prospective ship operator cannot be established solely by an objective economic analysis. There are many factors upon which it is difficult to place an economic value. The choice between a nuclear and fossil fueled SL-7 for an unsubsidized operator is not obvious for the alternative power plants are competitive and an economic evaluation can be shifted in favor of either power plant by only a small shift in parameters. There is no clear alternative. The most important factors in making a decision are the difference in capital cost of the ships and the rate at which fossil fuel prices escalate. The difference in the cost of construction is approximately equal to the cost of the nuclear steam supply system. The effect of this cost difference can be substantially reduced and the selection thrown in favor of the nuclear powered ship if a construction differential subsidy is used. In addition, if legislation such as HR8201 introduced into Congress in 1971, which provides for assistance in the development, construction, and operation of nuclear powered merchant ships as discussed in Appendix A, becomes law, a nuclear powered merchant ship would have an economic advantage.

Political instability and nationalistic trends evident in many of the world's major petroleum producing countries must give cause for serious concern. The price of residual oil has increased sharply since 1968 and will continue to increase. The only question is at what rate.

The higher the rate of escalation, the more favorable the nuclear powered ship becomes.

Other factors upon which an economic value cannot readily be assigned or which are difficult to anticipate, as to when they will occur and to what extent, must also be considered.

Environmental pollution considerations are such problems. The SL-7 has been designed to eliminate one of these problems, that is, oil pollution of the sea. As discussed in Chapter IV, the ship has separate ballast and fuel oil tanks to prevent contaminating the harbors when she deballasts to take on fuel oil. Its effect is to limit the flexibility of the ship for she must take on bunkers at each end of her run. Furthermore, she cannot operate at design speed on long trade routes such as Trade Route 12, East Coast of the United States to the Far East. The economic effect of these restrictions can only be established by the company making the decision. Obviously, if they intend to operate on long trade routes, or anticipate problems in refueling at both ends of the run, or there is a possibility of being tied up in port for a long duration due to strikes that prevent refueling, then the nuclear power plant would be favored.

Another environmental problem that has not yet affected shipowners is that of air pollution. For example, the ships entering and leaving New York harbor each day are contributing to the air pollution problems of that area. Ships are not now required to burn the more expensive low sulphur fuel nor to install pollution control equipment. It can be expected that low sulphur fuel will be required at a minimum when entering port, and that installation of pollution control equipment at least on new construction ships will be required in the future.

Both of these control measures will increase the cost of the fossil fueled ship, and the possibility of a reduction in cargo capacity due to pollution control equipment would make the nuclear powered ship more attractive.

Additional factors that can be considered for the SL-7 are loading and stability problems. The SL-7 must be programmed as to the distribution of containers, fuel oil, and ballast, and ballast must be taken on while underway as fuel oil is consumed in order to assure adequate stability. Also at present the fueling facilities at most ports are inadequate to fuel the SL-7 at the rate she is designed to accept. As a result, fuel loading time can be greater than cargo handling time and the ship's inport time will be dependent on the fueling facilities available.

Reduction in cost due to a reduction in topside maintenance and damage to deck cargo caused by corrosive stack gases, which are eliminated by the nuclear power plant, must also be considered.

The effect of the revenue earned each year and the rate of escalation must be thoroughly examined. As seen in Chapter X the average annual cost of the SL-7N is lower than that of the SL-7. However, at the yearly revenue and rate of escalation of revenue selected, the average annual net profit is slightly higher for the SL-7. If the yearly revenue were lower, or the rate of escalation were lower, the SL-7N becomes more profitable in comparison to the SL-7. Thus on other trade routes where the yearly revenue might be less, or if competition increases forcing revenue down, the SL-7N might be more economical.

It must be remembered that this comparison is being made on a ship designed for a fossil fuel power plant and this favors the fossil

fueled ship. For equal transport capacity the nuclear ship would have a smaller displacement, thus less draft, reducing the power requirements. The capital cost of the ship would therefore be less along with a lower annual fuel cost and a longer core life, making the nuclear powered vessel more economical.

Then there are problems faced by the nuclear powered ship which could adversely affect its position. Third party nuclear liability is of particular concern. If the government does not provide liability protection for marine power plants as is provided for utilities under the Price-Anderson Act, a nuclear merchant marine would be greatly handicapped.

Another potential area of difficulty is with the maritime unions. American Export Isbrandtsen Lines solved this problem while operating the N.S. SAVANNAH by establishing a subsidary company and working out separate contracts with the unions. Crew problems can be expected to occur, however if they are approached in a thoughtful manner and problem areas are anticipated, the problems should be able to be resolved as demonstrated by AEIL's experience.

Port entry difficulty could occur in some ports. Although this would not be expected in Europe if prior arrangements are made because the N.S. OTTO HAHN has operated in the area since 1968. In the Far East, Japan was a problem for the N.S. SAVANNAH, however, since that time Japan has constructed the N.S. MUTSU and port entry should not be as great a problem.

Pollution problems might occur in the future. The nuclear powered ship will be designed to discharge contaminated water into retention tanks while in port. These tanks would then be processed in the same

manner as shore based power plants and discharged at sea. Or the shipowner may be required to establish discharge collection facilities at the ship's home port or facilities aboard the ship for recycling the water back into the primary system.

From the foregoing discussion, it is concluded that the selection of either power plant for the SL-7 for use on the North Atlantic run is competitive. However, if an operator desired to build a new ship with the transport capacity of the SL-7 that would be designed specifically for the power plant chosen, then the nuclear power plant would have an economic advantage, and this would be encouraged if a construction differential subsidy were used.

BIBLIOGRAPHY

1. "Economic Criteria for Decision Making in the Transportation Industry," Harry Benford, University of Michigan, Ann Arbor, May 1966.

2. "Mathematical Analysis for Business Decisions," J. E. Howell and D. Teichroew, Richard D. Irwin, Inc., Homewood, Illinois, 1963.

3. "Fundamentals of Ship Design Economics," Harry Benford, University of Michigan, Ann Arbor, August 1965.

4. "Fuel Cycle Economics," Daniel F. Hang, University of Illinois, October 1970.

5. "Economic Analysis of the Nuclear Fuel Cycle, Including Pre- and Post-Reactor Periods," V. P. Zodiaco, A Thesis in Nuclear Engineering, Pennsylvania State University, University Park, Pennsylvania, December 1971.

6. "High Speed SL-7 Type Container Ship for Sea-Land Service, Inc." J. J. Henry Co., Inc., New York, New York, September 1969.

7. "General Cargo Ship Economics and Design," Harry Benford, University of Michigan, Ann Arbor, June 1968.

8. "Advanced Nuclear Cargo Ship Study," General Dynamics, Quincy, Massachusetts, 1968.

9. Letter from J. W. Boylston of Sea-Land Service, Inc., Elizabeth, New Hersey, January 1972.

10. "How the Arabs Changed the Oil Business," Gurney Brechenfeld, Fortune, August 1971.

11. "Fuels: What's Ahead?" T. C. Elliott, Power, December 1970.

12. "Resid Shortfall Foreseen Soon in U.S.," Oil and Gas Journal, May 17, 1971.

13. "Industries' Future Must Hold Still-Higher Oil Prices," Oil and Gas Journal, February 1, 1971.

14. "TIPRO Urges 5%/Year Crude-Price Hike," Oil and Gas Journal, November 22, 1971.

15. "Higher Prices for Oil - Who Will Get Hit," U. S. News & World Report, March 1, 1971.

16. "Prices for Short-Haul Crudes," Petroleum Press Service, May 1971.

17. "Plutonium Question: Recycle or Store?" Donald Hunter, Electrical World, August 1, 1971.

18. "The Nuclear Industry," WASH 1174-71, U.S. Atomic Energy Commission, Washington, D.C., 1971.

19. "The Effect of Escalation on Future Electric Utility Fuel Costs," L. G. Houser, Westinghouse Electric Corp., Pittsburgh, Pennsylvania, 1971.

20. "The Potential and Problems of Nuclear Power," W. E. Johnson, Commissioner AEC, National Energy Forum, Washington, D.C., September 24, 1971.

21. "Price Forecasting and Resource Utilization for the Fuel Cycle Industry of the United States," R. Salmon, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1965.

22. "The Practical Application of Economics to Merchant Ship Design," Harry Benford, Weekblad 'De Ingenieur', 1966.

23. "Showndown with Oil Nations - The Stakes in Prices, Markets," U.S. News & World Report, February 1, 1971.

24. "Libya Kicks BP Out and Boycotts OPEC," Oil and Gas Journal, December 13, 1971.

25. "No Heat Apparent in New OPEC Talks," Oil and Gas Journal, November 15, 1971.

26. Editorial, Electrical World, November 1, 1971.

27. "More Escalation for Coal Costs," Electrical World, August 15, 1970.

28. "The Nuclear Industry - 1970," E. B. Tremmel, Atomic Industrial Forum, Washington, D. C., November 18, 1970.

29. "The Economics and Influences of Nuclear Refueling in Maritime Applications," NUS-295A, L. R. Pletke and R. P. Sullivan, NUS Corporation., October 1966.

30. "Venezuelan Action Will Boost Oil Tariffs," Oil and Gas Journal, January 24, 1972.

31. "Producers Fear Impact of Big Venezuelan Bite," Oil and Gas Journal, January 3, 1972.

APPENDIX A

THE UNITED STATES MERCHANT MARINE

A REVIEW

A PERSPECTIVE

From the launching of the VIRGINIA, the first ship to be built in the new world, American ships have shown novelty in design and independence in method. After the Revolutionary War, trade with England was discouraged, so our ships spread throughout the rest of the world and our young nation joined the ranks of the leading maritime nations of the world.

There were many attempts in the late eighteenth and early nineteenth centuries to apply the steam engine to ships. However, the era of commercial navigation did not begin until the launching of Robert Fulton's CLERMONT in 1807. She was a paddle wheel ship powered by a steam engine developed by James Watt. By 1819 there were 100 steam vessels on America's inland waters. In 1808 John Stevens became the first owner and operator of a sea-going steam ship when he sent the PHOENIX from New York to Philadelphia. In 1810 Stevens succeeded in running a steam launch equipped with twin screws revolving against each other. He also designed the first water tube boiler and used a steam pressure of 50 psi as compared to 10 psi used by Fulton. However, lack of machine tools and foundaries hindered the advancement of his ideas from experimental work to full scale commercial use. John Stevens' developments were fifty years ahead of his profession and his country. America was only mildly interested in steam propulsion for she was on her way to the perfection of sail[1].

Another American innovation in the early nineteenth century

occurred when a group of New York merchants established the first freight and passenger service based on a definite schedule. They advertised precise sailing hours, with direct and reasonably rapid voyages to Liverpool and Havre. Ships were designed and built for this type of trade. The Black-Ball line was the first and most celebrated of this type of service.

For many years ships of Europe and America had been engaged in the tea trade with China. Speed was particularly desirable in this trade because of the long distances from New England around the Cape of Good Hope to China, and because it was believed that tea lost some of its flavor with time. A quicker turn-around meant higher profits. This lead to the development of the clipper ships. The first being the RAINBOW, launched in New York in 1845. In this area, the clippers captured the trade from the British. From records of the time, it is revealed that the clippers would enter Canton, unload the cargo and take on a full load of tea and sail immediately for New England or London, even though they charged 2.5 times as much as the British ships which for months had been waiting for a full load. The clippers made the passage in three months instead of six that the British required[1]. Development was also spurred on by the California Gold Rush with the need to transport many men and supplies quickly to California. However, these ships were expensive to run. They could not survive on low freight rates, and the end of the gold rush was the beginning of the end of the clipper ship.

During this time of expanding sail America continued to pioneer in the area of steam propulsion, but failed to follow through on her developments. In 1819 the SAVANNAH, with a steam engine as an auxiliary,

made the first transatlantic passage, using her engine eighty hours out of the twenty-nine day voyage from Savannah, Georgia to Liverpool. In 1834 the propeller-driven auxiliary steamer MIDAS sailed from New York to China. Other than these few pioneering efforts, it was left to the British to develop and refine steam propulsion. In 1838 the SIRUS made the first transatlantic crossing completely under steam. In 1840 with the inaugural voyage of the steamer BRITANNIA, began the first regular steamer service between Europe and North America[2]. The British pushed the development of screw propulsion and iron ships, though on long voyages as to Australia and India, sailing ships continued to dominate because of the inefficiency of steam propulsion. However, with the opening of the Suez Canal in 1869, the end of the sailing ship era was in sight.

Thus the nineteenth century that had begun so well for maritime America closed with our country occupying a very low position in the maritime world. Whereas 90% of our foreign commerce was carried in American bottoms at the beginning of the century, only 10% was being carried as we entered the twentieth century. Steam propulsion ashore, that is, our railroads, were developed and pushed forth across the country because the government offered them land grants, a form of subsidy. The government, however, lacked the foresight to foster and develop steam propulsion at sea[1].

With no merchant marine to speak of, we moved into the twentieth century. We had only six ships in regular service to Europe, five to South America, and five to the Orient. Then World War I began. Those foreign ships that provided our trade were engaged at home, our exports began piling up in warehouses and imports dwindled. People complained

and the few ships we had became very valuable. Shipyards finally started to work, 160 new yards were built, 3,270 ships were ordered and 2,300 completed by the end of the war. This construction moved us from fifth to second place in the number of ships and total tonnage. In addition to civilian requirements World War I was a convincing demonstration of the necessity of maintaining an American Merchant Marine even at public expense, for after the United States entered the war, the Navy, as it has in every other conflict, wanted and needed numerous vessels as auxiliaries and transports. Most of our troops were carried to Europe and back in allied ships[7].

After the war, we quickly forgot the lesson we had so difficultly been taught and our merchant marine again began to decline. Not one new keel was laid for foreign commerce between 1922 and 1928. Then Congress took action and for awhile it appeared that we had learned a lesson. The Merchant Marine Act of 1928 resulted. It offered construction loans at advantageous rates and operating subsidies. Under this stimulus, forty-two vessels were built between 1929 and 1932. Then government support was cut, the depression had its effect, and by 1934 only five ships were under construction[1]. Public hearings were held by Congress and the Merchant Marine Act of 1936 resulted. By November 1938, sixty modern ships were under construction. These ships allowed the United States to enter World War II better prepared than we entered World War I, and along with the tremendous ship building program during the war, to save Europe. By the end of the war, the American fleet contained 3,696 ships, the largest in the world. It was realized during the war that block obsolescence of these ships would occur in the 50's and 60's, however nothing was done to prevent this from happening[15]. Our government

again ignored the lessons of history and allowed the merchant marine to decline despite its demonstrated importance to our economic welfare and national security.

By 1950 our merchant fleet was only carrying about 12% of our total and 32% of our general foreign trade. The Korean War required the reactivation of some ships of the reserve fleet, but few new ships were built, and after the war most of the reserve ships were retired. It was finally recognized in 1958 when our fleet was carrying only 8% of our total and 25% of our general foreign trade, that the obsolescence of war-built tonnage necessitated a rebuilding program. The Eisenhower Administration then committed itself to a replacement program, envisioning the construction of 300 modern ships over a ten-year period to replace the subsidized liner fleet. However, the commitment did not last, and the program began fading. The best effort of the program occurred in 1963 when twenty-seven ship contracts were executed, and this then was reduced to ten or eleven ships per year, instead of the thirty proposed. Between 1958 and 1967, the United States flag fleet share of the commercial general cargo trade declined from 25% to 8%, even though there was an increase of from 33 to 37.5 million tons of general cargo.

Again in 1965 we found ourselves in need of a fleet to support the buildup of military forces in Vietnam. This required the reactivation of our obsolete reserve fleet. Our operating merchant fleet did not have the capacity required to transport the war materials and men required for 95% of the supplies, and initially 66% of the troops were moved by ship[7].

A new threat is also posing on our doorstep. When between 1958 and 1968 our merchant marine expanded by only 1.7 million deadweight

tons and the average age of our ships increased from fourteen to twenty-seven years, the Soviet Union constructed eight million deadweight tons. In 1966 the U.S. had only 1,167 merchant ships, the Soviet Union 1,343[3]. Today our fleet numbers 650 ships in foreign trade, about 400 of which will reach the end of their economic life within the next few years[17]. The total foreign trade carried by the U.S. is down to about 5%. By 1980 our fleet will have declined to 310 ships if our shipbuilding program is not expanded.

Competition between the United States and the Soviet Union is all encompassing. It is political, military, and economic. We have recognized their political and military challenge, but have not awaken to their economic challenge, particularly at sea. Today the Soviet fleet outnumbers ours, even including the activated reserve fleet. The Soviet Union is not merely breaking loose from its traditional continental emphasis on containment, it is aggressively moving to dominate the sea lanes of the world. For by gaining world shipping dominance, it could obtain economically what it has failed to obtain politically and militarily, since it could possibly deny the strategic materials the United States must import[3].

Since World War II the United States has again demonstrated its technological ability by pioneering in the development of marine nuclear propulsion, and new methods of cargo handling such as container ships, roll-on-roll-off vessels, the LASH system, the SEABEE system, and the integration of these new marine transportation systems with shore transportation to form an intermodal system concept.

In 1968, with a new Administration at the helm, a complete re-evaluation of the merchant marine was undertaken resulting in a

commitment to again revitalize our fleet. The Maritime Administration increased its research budget from a 1969 level of $6.7 million to a requested $20.7 million in 1971. It also has developed twenty new ship designs using the latest techniques. The shipbuilding industry invested $200 million in capitol improvements in 1969-1970 compared to $579 million between 1958 and 1969[20]. Today we have a few of the finest ships on the high seas. The Administration requested and the Congress passed the Merchant Marine Act of 1970. The commitment is to build a modern fleet capable of carrying 30% of the U.S. foreign trade by 1980. To do this requires the construction of 300 new ships over the next ten years. Each modern ship is expected to be the equivalent of three ships it is replacing. Combined with 150 ships of recent construction, we should have a fleet, by 1980, capable of meeting our commercial and defense needs[17].

Government policies in the past failed to achieve their objectives because of poor programs, lack of consistent support, lack of flexibility in meeting changing conditions, and lack of adequate funding. The question is whether or not this new commitment will be sustained through the 70's, or will it evaporate in a few years as it has in the past.

MARITIME LEGISLATION

Merchant Marine Act of 1936

A basic knowledge of the laws that affect the merchant marine industry is required in order to gain a better understanding of the challenges and opportunities facing the industry today. The primary law that supports the industry is the Merchant Marine Act of 1936. The law was passed in an attempt to discourage the decline of the merchant marine which was caused by numerous problems, the most important of which were increasing shipbuilding and wage costs which were pricing the industry out of competition with foreign flags.

The Merchant Marine Act, in its Declaration of Policy, stated that the policy of this country was to maintain a merchant marine constructed, owned, and manned by the United States, so as never to be at the mercy of foreign ships or shipyards. That an efficient and economical merchant marine of sufficient size to meet all of this country's domestic water-borne traffic, a substantial portion of its foreign trade and the capability of supporting the armed forces in time of national emergency was essential to our national security. Some important provisions of the original Act were as follows:

Maritime Commission - Title II provided for the establishment of the United States Maritime Commission. This Commission was abolished in 1950 and its functions transferred to a Federal Maritime Board and the Secretary of Commerce. The Board was replaced in 1961 by the Federal Maritime Commission. The Commission's functions include the regulation

and control of rates, services, practices, and agreements of common carriers by water and of other persons affecting shipping in domestic and foreign trade.

Construction - Differential Subsidy - Title V provided for the construction by American citizens in the United States of cargo liners and passenger ships. The purpose of the subsidy was to stimulate construction in U.S. shipyards by paying for the difference in the cost of construction in foreign yards. It allowed a maximum subsidy of 55% for cargo liners and 60% for passenger ships.

Section 509 provided that any citizen may apply for a loan to construct a new vessel. A purchaser not receiving a subsidy is required to pay to the Secretary of Commerce not less than 12.5% and a purchaser receiving a subsidy, 25%, of the unsubsidized cost of the vessel. The balance to be paid in not over twenty-five years in equal annual installments at an interest rate established by the Secretary of the Treasury.

Section 511 permits the establishment of a non-taxable construction reserve fund for the construction, reconstruction, or acquisition of a vessel within a certain time period. The fund to be composed of deposits of proceeds from sales of vessels, earnings from the operation of vessels and receipts in the form of interest or otherwise, with respect to amounts previously deposited. The allowable depreciation on the ship is reduced by the amount of the reserve fund.

Operating - Differential Subsidy - Title VI authorized and directed the Secretary of Commerce to consider the application of any citizen for

financial aid in the operation of a vessel in the foreign commerce of the country to make them competitive with foreign operators. The amount of subsidy was to be based on the difference between the fair and reasonable cost of insurance, maintenance, repairs, wages, and subsistence, and the cost of the same items if operated under foreign registry. One-half of any excess profit over 10% was to be recaptured by the government.

Federal Ship Mortgage Insurance - Title XI allows the Secretary of Commerce to insure the interest on and unpaid balance of the principal on certain ship mortgages and loans and to fix a premium for the insurance within specified guidelines.

Even though the Merchant Marine Act of 1936 has resulted in the expenditure by the government of over $5 billion in the form of subsidies, the decline of our Merchant Marine continued. The purpose of the Act has not been questioned, however the manner of achieving its goals has been the center of controversy since its inception, particularly the subsidy provision. One viewpoint is that the merchant marine and shipbuilding industries dependence on subsidy has fostered outmoded and uneconomical practices. This is evidenced by the following statement of former Secretary of Transportation Alan S. Boyd presented before the Subcommittee on Merchant Marine of the U. S. Senate on May 10, 1968:

> "Enduring through the years as a tradition, the merchant marine has declined as an industry. Its decline parallels its increasing dependence on Government support through subsidies of one kind or another. Subsidies - direct and indirect - have been a compromise answer to a difficult situation. They have prevented both the death and the nationalization of the merchant marine.
>
> The subsidy system itself is in clear need of reform. Instead of encouraging innovation and productivity, the

> system focuses attention on the subsidy dollar as a source of income. A new system must be found that will induce the industry to take full advantage of advancing technology, management ingenuity, and the resources of a skilled labor force."

Furthermore, the Act was applicable only to cargo liners and passenger vessels. In the 1930's there was only a small tanker and bulk carrier fleet, tramp shipping was expected to soon disappear, and government shipping was very small. Since then, our foreign bulk carrier trade has risen to over 200 million tons per year and tanker trade to over 150 million tons per year, and the U. S. Government is the world's largest shipper[21].

Until 1970 the Act remained essentially unchanged despite these tremendous changes in U. S. trade. Then a long overdue attempt to correct the inadequacies of the original Act was made with the passage of the Merchant Marine Act of 1970, Public Law 91-469. Whether this is the proper corrective action is not the purpose of this discussion, however, a look at some of its provisions and how it modified the original Act is of value.

Merchant Marine Act of 1970

The purpose of this new Act is to correct the deficiencies of the past with the goal of having U. S. flag operators carrying 30% of our total foreign commerce and 50% of our liner trade. This is to be accomplished by the expenditure over the next ten years of $4.5 billion for the construction of 300 ships. Some important amendments that this Bill makes to the Merchant Marine Act of 1936 are as follows:

Construction - Differential Subsidy - This section of the Act is amended

to allow bulk carriers, tankers, and other vessels to be eligible for a construction subsidy. Also, the amount of subsidy is to be reduced in stages from the 55% previously permitted to 35% in fiscal year 1976. The purpose of this reduction is to foster improvements in the industry and lessen its dependence on government subsidy.

Operating - Differential Subsidy - The new Act extended to tankers and bulk carriers the provisions of this section and also permitted the payment of subsidies for certain cases of foreign port to foreign port voyages. In addition, it allows bulk carriers who now own foreign flag vessels to participate in the operating subsidy program provided they agree to purchase no new vessels for their foreign-flag operations, and to divest themselves of their present foreign holdings within twenty years.

Furthermore, the new Act changes the way by which the subsidy is calculated. In the past, the government was placed in the position of paying all wage and benefit changes negotiated by management and labor, although it had no voice in the bargaining. Under the new program wages and benefit payments are based on costs incurred by foreign competitors adjusted by a national wage benefit index to reflect wage level trends of other sections of the U. S. economy. Thus encouraging operators to hold wage and benefit payments within the index level.

The recapture provision of the original Act was eliminated.

Federal Ship Mortgage Insurance - The ceiling on the amount of insurance the Maritime Administration can write was raised to $3 billion.

THE STATUS OF A NUCLEAR MERCHANT MARINE

The N.S. SAVANNAH

After World War II, scientists and engineers began thinking about using nuclear energy at sea. Imagination turned to reality with the launching of the first nuclear powered ship, the USS NAUTILUS (SSN 571), in 1954. Following in her footsteps, President Eisenhower proposed in 1955 that the United States build the world's first nuclear powered merchant ship to demonstrate America's intentions for the peaceful use of nuclear energy. The ship was not intended to prove or disprove the economics of marine nuclear propulsion, but was to help identify, define, and solve problems of design, operation, and manning to benefit future ships. Congress agreed with the President and passed Public Law 848 on July 30, 1956, which added a new Section 716 to the Merchant Marine Act of 1936. On October 15, 1956, the President directed the construction of the N.S. SAVANNAH as a joint project of the Maritime Administration and the Atomic Energy Commission.

The keel of the SAVANNAH was laid on May 22, 1958, and she was launched on July 21, 1959, being christened by Mrs. Eisenhower. Her reactor first went critical on December 21, 1961, and attained 100% power on April 4, 1962. The ship was designed by George G. Sharp, Inc., built by New York Shipbuilding Corporation, and her nuclear reactor was supplied by the Babcock and Wilcox Company. Table 1 lists some of the ship's important characteristics.

Table 1

N.S. SAVANNAH

Length	595 feet
Beam	78 feet
Draft	29.5 feet
Cargo Capacity	9,300 tons
Displacement	20,000 tons
Cruising Speed	21 knots
Power	22,000 SHP
Reactor	80 MWt
Core Life	15,600 EFPH

The Maritime Administration had contracted with the States Marine Line of New York to operate the SAVANNAH as part of its fleet. On May 1, 1962 the ship was delivered to her operators. Her maiden voyage was made from Savannah, Georgia in August 1962, sailing to Norfolk, Virginia, then through the Panama Canal to various west coast ports. In March 1963, she tied up at Galveston, Texas where the Maritime Administration had established service facilities, for inspections and planned modifications. She was then to sail to Europe. However, labor disputes arose between the deck and engineers unions and the operating engineers went on strike. The dispute could not be settled and as a result, a new general agent was named, America Export Isbrandtsen Lines, and a new crew was trained. In May 1964 the SAVANNAH finally made her first transatlantic crossing. During her demonstration voyages, she made a total of ten crossings visiting more than a dozen European ports, she steamed 89,818 miles, and stopped at a total of 46 ports. In August 1965, the SAVANNAH was placed in commercial service by First Atomic Ship Transport, Inc.(FAST), a subsidiary of AEIL, to carry cargo on the company's North Atlantic and Mediterranean runs.

On March 1, 1967 in hearings before the Subcommittee on Merchant Marine, House of Representatives, the then acting Secretary of Commerce, Alexander B. Trowbridge, proposed the withdrawal of the SAVANNAH from service and stated:

> "The SAVANNAH has not been and cannot be for the foreseeable future operated so as to show a profit or merely to break even. You will recall that the SAVANNAH is a combination passenger-cargo vessel. In practical financial terms, the fact that a significant portion of the space on board cannot be utilized to haul cargo makes losses larger than they would otherwise be, if the vessel was designed for all-cargo operations.
>
> Experimental operation of the SAVANNAH, under commercial conditions, will have been sufficient to establish - without need for further commercial operations at a significant financial loss - the feasibility of a nuclear-powered merchant ship. We do not believe that the continued experimental operation of the SAVANNAH is needed or will produce additional research value sufficient to offset the continuing heavy operating deficit. For this reason, we do not propose to continue it in operation beyond this August."[6]

However, because the SAVANNAH's first core had not been depleted, and many foreign ports, particularly in the Far East, had not been visited, and because of the support for the program by the ship's operators, many congressmen, and the merchant marine industry in general, the proposal was rejected.

By July 1970 the SAVANNAH had visited a total of seventy-seven ports in twenty-six countries and twenty-one states and territories of the United States. She had carried cargo on a commercial basis to thirty-seven foreign and thirteen domestic ports, and had sailed to the Far East three times calling at Hong Kong, Taiwan, and the Philippines. The ship had made a total of 737 reactor start-ups, steamed 454,675 miles with a reactor plant at sea availability of 99.8%, meeting all advanced schedules without a single plant failure. In all, she consumed 75 Kg of

U-235, the equivalent of 28,800,000 gallons of fuel oil. The ship's total cost was about $100 million, including ship construction and operation, the establishment of training facilities at King's Point, New York, the training of her crews, and the construction of service facilities at Galveston.

The SAVANNAH program has proven the technical feasibility and safety of a nuclear powered merchant ship, won acceptance at home and at most foreign ports, demonstrated the capability of a nuclear vessel to maintain schedules, established a servicing facility for future nuclear powered ships, established a training program for future nuclear powered ship operators, made practical the development of numerous technical and economic studies to explore the future use of nuclear propulsion, and has given us valuable knowledge concerning the economics of nuclear ships. The SAVANNAH accomplished her objectives, although there are many problems that remain to be solved, such as insurance considerations, and labor disputes.

In 1971 Congress was unwilling to continue supporting the ship. Alternative proposals to convert her to a container ship or an LPG carrier, or to turn her over to the Navy for conversion to an oceanographic research vessel or a destroyer tender have not been successful, even though a second core is available and would be transferred with the ship without cost. Thus on April 1, 1971 work began at Galveston to take her out of service, she was defueled in September 1971 and will be put in a reserve status at Savannah, Georgia.

GOVERNMENT INTEREST

Not since President Eisenhower signed the bill authorizing the construction of the N.S. SAVANNAH has an important piece of legislation relating to the development of a nuclear powered merchant marine been passed. The government's attitude since 1955 has been variable.

Congress - The Committee of Commerce of the Senate and the Committee on Merchant Marine and Fisheries of the House have held numerous hearings on the status of the merchant marine and have introduced bills fostering the development of a nuclear powered merchant marine. However, none of these bills have been passed.

A recent bill, H.R. 8201, introduced by Mr. Downing, is similar to bills previously introduced into the House and Senate and contains the following provisions:

This bill amends Title X of the Merchant Marine Act of 1936, and allows the Secretary of Commerce to grant aid for the development, construction, and operation of nuclear powered merchant ships whose design embodies a significant departure from the design of existing nuclear powered merchant ships which may lead to a significant reduction in the cost of constructing or operating future nuclear powered merchant ships.

The amount of aid to be as follows:

To pay the contractor all of, or part of, the excess of the cost of developing the proposed ship over the estimated fair and reasonable cost of developing a comparable conventional ship. And to pay the contractor all of, or part of, the excess of the cost of constructing the proposed ship in the United States over the estimated fair and reasonable cost of constructing a comparable conventional ship in the United States.

In addition, the Atomic Energy Commission could waive or reduce the charges for the use of source and special nuclear materials for not exceeding the first five years of operation, could assist in training of the crew of the ship, conduct studies and assist in the planning and designing of shore service facilities, make available appropriate classified material, provide research and development in Government laboratories, design review service, ship construction inspection services, and ship operation advisory service[14].

Administration - Action by the administrations since 1955 on the development of a nuclear powered merchant marine has been negligible. The attitude in 1968 can be ascertained from the statement of Secretary of Transportation Boyd before the Subcommittee on Merchant Marine of the Senate:

> "There is serious doubt as to the attractiveness and wisdom of proceeding with a broader nuclear ship program at the present time. It appears that power reactors of the relatively small sizes required for merchant ship propulsion will continue to be noncompetitive with oil over the foreseeable future."[25]

There appears to be more interest by the present Administration. The Merchant Marine Act of 1970 demonstrates the Administration's commitment to an improvement of our maritime posture, however, the word nuclear appears nowhere in the Act, thus it is not specifically fostered but neither is it rejected. During the summer of 1971, the Administration conducted several hearings at which the Maritime Administration presented its case for the development of a nuclear merchant marine, however, no decision has yet been forthcoming.

Atomic Energy Commission - In a report, prepared jointly in November 1967 by the Department of Commerce. the Department of Defense, and the Atomic Energy Commission, for the Committee on Commerce, United States Senate the following recommendations were made:

> "1. The Federal Government should take an active role in a development program leading to economically competitive nuclear powered merchant ships.
>
> 2. The Department of Commerce and the Atomic Energy Commission assisted by the Department of Defense and the President's scientific advisor, should cooperate in the establishment of a construction and research and development program to implement the following policy:
>
> (a) The Department of Commerce and industry, with Atomic Energy Commission support, should proceed immediately with the construction of two to four large, high-speed (27 to 30 knots) fast turnaround nuclear-powered ships utilizing commercially available nuclear powerplant technology in an integrated transportation system to be privately owned and in operation by 1972.
>
> (b) The Department of Commerce and the Atomic Energy Commission should proceed in an orderly fashion with a research and development program including a Government-owned, land-based test facility for an advanced reactor for nuclear-powered merchant ships.
>
> 3. For the recommended nuclear fleet, legislation should be provided to permit the Federal Government to pay the excess design, development, construction, and operating costs due to this initial application of nuclear reactor propulsion plants."[5]

However, the AEC never requested funds to proceed with the program and apparently changed its opinion. For in May 1968 Mr. George Kavanagh, Assistant General Manager for Reactors, in a statement before the Committee on Commerce said:

> "For the reasons described above, we believe that a broad nuclear merchant ship program should not proceed at this time and that the Administration position in this regard is a reasonable one."[25]

Maritime Administration - The opinion of the Maritime Administration in 1968 is revealed in the following statement which appeared at the conclusion of a report to Congress:

> "It is urgent that this first U.S. nuclear merchant fleet be built promptly, taking full advantage of the maritime reactor technology as it exists today. If we delay, the U.S. lead in nuclear maritime propulsion, and high-speed liner service will have passed to Germany, Japan and other countries with firm plans to build nuclear ships more advanced than the SAVANNAH, and vessels as fast as any presently contemplated for the U.S. merchant marine."[6]

"The Maritime Administration has supported a number of studies on the development of a nuclear powered merchant ship. The results of several of these reports are given below:

In a report titled, "Importance of an American High Speed Nuclear Ship Program," prepared by the Maritime Administration in 1965, the following recommendations were made.

> "It is recommended that the Maritime Administration:
> (1) Propose, initiate, and expedite a high speed nuclear ship program.
> (2) Initiate immediate and close liaison with the Atomic Energy Commission to determine in detail the most economic and expedient program for:
> (a) the required engineering, research, and development of a compact maritime PWR for immediate application;
> (b) the continued improvement of the design of the compact PWR;
> (c) the development of a further advanced plant capable of widespread application in the merchant marine.
> (3) Begin exploratory discussions with the operators who have expressed or who might express an interest in investing in such ships on routes which have potential for high speed nuclear powered ships, starting with AEIL's current proposal for immediate operation of the SAVANNAH on TR 12 followed by construction and operation of four high speed nuclear ships on that route."

In 1968, General Dynamics completed an extensive report titled, "Advanced Nuclear Cargo Ship Study." In summary the report compared two systems, one consisting of three high speed nuclear powered container ships, the other, three conventionally powered container ships of the same speed and capacity, operating on Trade Route 12. The results based on a cash flow analysis showed the rates of return on the owner's equity after taxes to be:

		Rate of Return
I	Nuclear Not Government Supported	-2%
II	Fossil Fuel Unsubsidized	+18%
III	Nuclear, supported under legislation similar to H.R. 8201 discussed previously	35%
IV	Fossil fuel subsidized at 55% its construction and design costs	30%

The report thus shows a nuclear powered merchant ship to be uneconomical without the government support proposed in H.R. 8201.

The latest thinking of the Maritime Administration is revealed by Mr. Marvin Pitkin, Assistant Administrator for Research and Development, in the "Marine Nuclear Steam Propulsion Executive Briefing," presented in 1971, in which he stated in summary:

1. World trade is rapidly increasing.
2. To meet the demand of this increasing trade has required a drastic increase in ship speed and size.
3. Increased speed and size necessitates increased power from approximately 20,000 SHP a decade ago to 120,000 SHP for vessels now underway.
4. The world market for high speed powered ships is expected to be about 2,500 in the next two decades.
5. A 10% penetration of this market would mean about $5 billion in the U.S. balance of payments.

6. Fuel cost is now more important than in the past. A 100,000 SHP ship would consume on the order of $100 million worth of fuel over twenty five years. Concurrently with the increase in power demand, fossil fuel prices have risen whereas nuclear fuel costs have tended to decrease.

7. As ship's horsepower is increased, nuclear propulsion becomes relatively more economical than fossil fuel systems. Nuclear ship reactors are economically competitive today in the 100 to 120,000 SHP range and will become more competitive in the future at lower power levels.

Mr. Pitkin completed his presentation with the following statement:

> "In summary, we have concluded that the time has come for maritime nuclear propulsion in the U.S. and have applied ourselves to the task of formulating a program in the nation's interests. The 1950's were characterized by the initiation of the U.S. nuclear industry for land-based power and naval reactor applications. The 1960's produced the necessary demonstration of technical and operational feasibility of maritime nuclear propulsion. We see the 70's as the decade in which to demonstrate economic feasibility, and in the 80's and beyond, we foresee development and exploitation of worldwide markets as nuclear propulsion penetrates into world fleet applications."

<u>INDUSTRIES'INTEREST</u>

American Export Isbrandtsen Line has been the only company to make a request for the construction of a nuclear powered merchant ship. They proposed to build three high speed container ships for operation on Trade Route 12. The proposal was based on the assumption that the House Bill, H.R. 766, similar to H.R. 8201 discussed previously, would be available. Since the bill never passed, the ships were not built.

The Maritime Administration has surveyed ship operators concerning their interest in nuclear power and in general received an affirmative reply. However, none appear to be willing or capable of bearing the

first costs alone.

Babcock and Wilcox, Combustion Engineering, Westinghouse Electric, General Electric, and United Nuclear Corporations have made studies relating to reactors for ships, however, only B & W has maintained a continuing interest. After building the power plant for the SAVANNAH, B & W developed a second generation system, an integral reactor concept the CNSG-I (Consolidated Nuclear Steam Generator). However, in 1966 when government funding for the nuclear maritime program was reduced, the company licensed its design to Germany for the N.S. OTTO HAHN, and later to Japan for the N.S. MUTSU. This resulted in a reduction of their development effort by about five years. The license agreement did, however, make available to B & W the results of the OTTO HAHN project. Aided by the experience gained on the OTTO HAHN, and the demonstrated feasibility of the integrated plant design, B & W developed the CNSG-IV, a 120,000 SHP power plant and they are designing a 240,000 SHP integral plant for the Maritime Administration. The Maritime Administration is now sponsoring a continuing development program with Babcock and Wilcox and General Electric aimed at offering a competitive nuclear ship system in 1973.

In the most recent economic study sponsored by the Maritime Administration and conducted jointly by a Naval Architect, Babcock and Wilcox and General Electric, the following result was obtained:

In the summer of 1971 Bunker "C" was selling for about $3.50 a barrel. With maritime nuclear fuel at an expected 1.5 mils per SHP-hr a projected savings of $3 million a year for high horsepower ships results[16].

OTHER COUNTRIES

Germany - The Federal Republic of Germany is pursuing a vigorous program of research and development, and is currently operating the world's only operational nuclear powered merchant ship, the N.S. OTTO HAHN (See Table 2). The construction cost of the ship, excluding fuel, was $14 million. The ship was built between 1963 and 1968 and has been operating for the past three years for the purpose of gaining experience and collecting the data required for the development of an economically competitive nuclear merchant ship.

Table 2[22]

Ship	
Length	564 ft
Beam	77 ft
Draft	30 ft
Displacement	25,812 tons
Power	10,000 SHP
Speed	17 kts
Crew (including trainees)	61
Research Personnel	35
Reactor	
Design Pressure	1,209 psi
Design Temperature	572 degrees F.
Operating Pressure	903 psi
Inlet/Outlet Temperature	513/533 degrees F.
Thermal Output	38 MWt
EFPD	500
Average Burnup	7,260 MWD/t UO_2
Weight UO_2	293 long tons
Average Enrichment	4.03%
Control Material	B_4C
Secondary Steam Pressure	441 psi
Feedwater Temperature	365 degrees F.
Steam Temperature	523 degrees F.
Superheat	65 degrees F.

The owner of the ship, G.K.S.S., is a company that was formed in 1957 specifically for the purpose of promoting the application of nuclear power for ship propulsion. Partners in the company are the Federal

Republic of Germany, the four northern German provinces, and thirty-four industrial and commercial companies.

The nuclear steam supply system is of the Babcock and Wilcox integral reactor design licensed to Germany in 1966. Under the terms of the agreement, the Atomic Energy Commission was to lease the first core and provide information on the SAVANNAH, in return they were to receive detailed information on the OTTO HAHN project.

The ship and reactor installation are equipped with additional measuring devices and research facilities to provide the technical and practical knowledge necessary for the design of future ships.

The reactor first went critical on August 26, 1968, and reached full power on October 12, 1968. The ship operated in the Baltic until February 1969, then began worldwide trial voyages. By mid 1970 she had steamed over 70,000 miles with a reactor plant availability of nearly 100%. The reactor system with self pressurization proved to be extraordinarily stable and met or surpassed all design parameters[22].

On the performance of the ship, Mr. D. Ulken, Director of the Institute of Nuclear Ship Propulsion, G.K.S.S., stated:

> "The author would like to state that the trial voyages with OTTO HAHN so far have shown that the principle of the advanced pressurized water reactor is well suited to marine service in the propulsion system of merchant ships. The behavior of the plant in heavy seas and under extreme climatic conditions has exceeded the expectations of both the builder and the operator. It appears, therefore, that the development and research on this reactor design, as is done in Germany at present, is particularly promising. The author expects that intensive detail work on this kind of reactor will lead to the production of an economic marine reactor of the power needed nowadays for merchant ships. Conventional ships have already reached a power range in which nuclear propulsion should be economically competitive. The experience gained with OTTO HAHN shows that nuclear ships can be as simple and reliable as conventional merchant ships. The advanced pressurized water reactor with its self-adjusting control will perhaps be better suited for

overall automatic control than the conventional boilers."

The Germans are planning new construction and in mid 1969 announced plans for a 215,000 ton nuclear oil/bulk/ore carrier, however, construction has not yet started[18].

Japan - The Japanese have an aggressive nuclear merchant ship development program with one ship under construction, the N.S. MUTSU, primarily a research and training ship. Her keel was laid in November 1968 and she was launced in June 1969, with an expected completion date in 1972. The MUTSU's reactor is a 36 MWt CNSG design licensed from Babcock and Wilcox. The ship will have 10,000 SHP, a speed of 16.5 knots, and a crew of fifty-nine with accommodations for twenty research workers.

Japan foresees considerable growth in nuclear power as shown by the following excerpt from the Japan Atomic Energy Forum's Nuclear Ship Study Group Report (March 1971):

> "If we dare to estimate the number of nuclear powered ships to be built during thirty years to come up to 2000 about two of eighteen container ships planned to be built in 1980 are expected to be super high-speed nuclear powered ships. In 1990 about ten nuclear powered vessels will be built against twenty-three container ships and these figures will be about twenty against twenty-nine in 2000. By 2000, Japan will have approximately 280 nuclear powered ships in total, including container and other kinds of nuclear powered ships."

The Japanese and Germans have recently been working out the details on a plan to build two 80,000 SHP container ships jointly. Japan will probably build the ships and Germany the nuclear steam supply system.

Italy - Italy has plans for the construction of a research vessel, the ENRICO FERMI, to be operated by the Italian Navy. She is to be powered by an 80 MWt, PWR, developing 22,000 SHP. A prototype reactor has begun operation. The French Atomic Energy Commission has been contracted to supply 5,000 Kg of enriched uranium for the ENRICO FERMI[18].

United Kingdom - In a document titled, "Report on the Nuclear Ship Study" prepared by the Department of Trade and Industry in 1971, the recommendation was made not to appropriate money for the research, development, and construction of a nuclear powered merchant ship at this time, but to use other nations' research if at a later date nuclear power becomes economically feasible. The study arrived at the following conclusion:

> "Nuclear propulsion for merchant ships could possibly become competitive in the following circumstances:
> (i) if the price of fuel oil rises by some 70% to 200% in real terms above the 1969 level; or
> (ii) if there is a dramatic improvement in the performance of nuclear reactors for use at sea, leading to a reduction of at least 50% both in the capital costs of reactors and in nuclear fuel; or
> (iii) any equivalent combination of the above factors."[18]

Soviet Union - The Soviet Union has been operating the world's first nuclear powered ice breaker in the N.S. LENIN for about ten years. Two advanced nuclear powered ice breakers are under construction. Their activity in the nuclear merchant ship area is unknown.

[illegible]

[illegible]

> [illegible]

[illegible]

SUMMARY

To develop a viable and economic merchant marine capable of meeting this country's needs will require forward looking people applying the most advanced technology to allow us to become competitive. This appears to be happening in at least the area of material handling, where container ships and the LASH system are replacing the old, inefficient, labor intensive, general cargo ship with the new capital intensive vessels. Surplanting those areas of high cost where we cannot compete, i.e., labor costs, with high cost capital investment in which we can compete. However, we are failing to develop along with these systems the advanced power plants needed for the high speed service that is coming into existence now. Are we going to repeat the errors of the past, when we pioneered in steam propulsion and scheduled sailings of ships, then dropped the effort in favor of the cheaper sailing ships, with the resulting British dominance of the merchant marine industry for over seventy-five years? Is the name SAVANNAH going to represent another time when the United States fails to carry on the development effort it pioneered? This time, however, we will not be losing to the British, but to the Germans and Japanese. It is time for industry and the government to join forces in an effort to develop and build a nuclear powered merchant marine.

REFERENCES

1. "America's Maritime History," A. C. Denison, G. P. Putnam's Sons, New York, 1944.

2. "A History of Ships and Seafaring," C. Canby, Hawthorn Books, Inc., New York, 1963.

3. "Soviet Menace," J. Dellenback, American Merchant Marine Conference, 36: October 1970.

4. The Merchant Marine Act, 1936, Superintendent of Documents, U. S. Government Printing Office, Washington, D.C., January 1971.

5. "United States Nuclear Merchant Fleet," Superintendent of Documents, U. S. Government Printing Office, Washington, D.C., November 1967.

6. Maritime Program, 1968, and N.S. SAVANNAH, Hearings Before the Subcommittee of Merchant Marine of the Committee On Merchant Marine and Fisheries, House of Representatives, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1968.

7. "Challenge and Opportunity," T. E. Stakem, American Merchant Marine Conference, 36: October 1970.

8. "Nuclear Power and Merchant Shipping," U. S. Atomic Energy Commission, Oak Ridge, Tennesse, March 1969.

9. "Nuclear Propulsion for Container Ships," I. A. B. Gaunt, The Institute of Marine Engineers, London, October 1970.

10. "Challenge and Opportunity," Thomas P. Guerin, American Merchant Marine Conference, 36: October 1970.

11. "A Long-Range View of Nuclear Ships," Japan Atomic Industrial Forum, Tokyo, March 1971.

12. H. R. 708, H. R. 398, The House of Representatives, Washington, D.C., January 1971.

13. H. R. 7023, The House of Representatives, Washington, D.C., March 1971.

14. H. R. 8201, The House of Representatives, Washington, D.C., May 1971.

15. "Meeting the Modern Challenge," W. B. Fowler, American Merchant Marine Conference, 36: October 1970.

16. "Marine Nuclear Steam Propulsion Executive Briefing," A Briefing presented by the Maritime Administration, Babcock and Wilcox Company, and General Electric Company, 1971.

17. "A Challenging National Program," R. J. Blackwell, American Merchant Marine Conference, 36: October 1970.

18. "Report on the Nuclear Ship Study," Her Majesty's Stationery Office, London, 1971.

19. "America's Atomic-Powered Merchant Ship," U. S. News and World Report, August 16, 1971.

20. "Shipbuilding Opportunities and Problems," J. T. Gilbridge, American Merchant Marine Conference, 36: October 1970.

21. "Nuclear Power and the Merchant Marine Crisis," T. B. Thamm, Naval Engineers Journal, February 1970.

22. "N.S. OTTO HAHN," D. Ulken, The Institute of Marine Engineers, London, October 1970.

23. "The Opportunity for a Bright Commercial Future," A. E. May, American Merchant Marine Conference, 36: October 1970.

24. "An Assessment of Nuclear Propulsion: A Challenge for the Seventies," M. Pitkin, An Address Presented at the Symposium On Nuclear Ships, Hanburg, Germany, May 1971.

25. Committee on Commerce Hearings Before the Subcommittee On Merchant Marine and Fisheries, May 10, 1968, Superintendent Of Documents, U. S. Government Printing Office, Washington, D.C., 1968.

26. "Importance of An American High Speed Nuclear Ship Program," Maritime Administration, Washington, D.C., 1965.

27. "Advanced Nuclear Cargo Ship Study," General Dynamics Corporation, Quincy, Massachusetts, June 1968.

APPENDIX B

COMPUTER CODE

ECONOMIC COMPARISON

FOSSIL FUEL AND NUCLEAR POWERED

CONTAINERSHIP

BASIC PROGRAM

```
C
C  THIS PROGRAM IS AN ECONOMIC COMPARISON OF A FOSSIL FUELED AND A NUCLE
C  POWERED HIGH SPEED CONTAINERSHIP. THE SEA-LAND SERVICE DESIGN, SL-7,
C  IS USED AS THE BASIS FOR THIS STUDY. THE NUCLEAR POWERED SHIP IS
C  DESIGNATED THE SL-7N
C
C  ACC     =  THE ANNUAL CREW COST SL-7
C  ACCN    =  THE ANNUAL CREW COST SL-7N
C  AUC     =  THE AMOUNT OF U REQUIRED FOR CONVERSION U308 TO UF6
C  AUCD    =  THE AMOUNT OF EQUIVALENT U REQUIRED FOR CONVERSION TO
C             ACHIEVE THE DISCHARGE ENRICHMENT
C  AUF     =  THE AMOUNT OF U REQUIRED FOR FABRICATION
C  B       =  THE DEBT TO TOTAL CAPITAL RATIO
C  BI      =  THE BANK OR BOND INTEREST RATE
C  CB      =  THE COST PER BARREL OF BUNKER C
C  CCO     =  THE COST OF CONVERSION $/KG U
C  CE      =  THE COST OF ENRICHMENT $/SWU
C  CEN     =  THE CARGO HANDLING EXPENSE SL-7N
C  CF      =  THE COST OF FABRICATION $/KG U
C  CH      =  THE COST OF THE HULL SL-7
C  CHE     =  THE CARGO HANDLING EXPENSE
C  CHN     =  THE COST OF THE HULL SL-7N
C  CLD     =  THE AMOUNT OF U DISCHARGED KG U
C  CM      =  THE COST OF MACHINERY SL-7
C  CS      =  THE COST OF SHIPPING SPENT FUEL $/KG U DISCHARGED
C  CU      =  THE COST OF U308 $/KG
C  CMN     =  COST OF MACHINERY SL-7N
C  CPV     =  THE NUMBER OF CONTAINERS CARRIED PER VOYAGE
C  CR      =  THE COST OF REPROCESSING $/KG U
C  CRN     =  THE COST OF THE REACTOR
C  DT      =  THE TIME IN WHICH THE SHIP IS DEPRECIATED
C  ECB     =  THE ESCULATION FACTOR FOR BUNKER C
C  ECCO    =  THE ESCULATION FACTOR FOR CONVERSION
C  ECE     =  THE ESCULATION FACTOR FOR ENRICHMENT
C  ECF     =  THE ESCULATION FACTOR FOR FABRICATION
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C  ECL    =  THE ESCULATION COST OF LABOR
C  ECM    =  THE ESCULATION  COST OF MATERIAL
C  ECR    =  THE ESCULATION FACTOR FOR REPROCESSING
C  ECS    =  THE ESCULATION FACTOR OF SHIPPING
C  ECU    =  THE ESCULATION FACTOR FOR U
C  ER     =  THE EQUITY RETURN RATE
C  LTV    =  THE AMOUNT OF FOSSIL FUEL CONSUNED PER VOYAGE LTONS
C  MAR    =  THE COST OF MAINTENANCE AND REPAIR SL-7
C  MARN   =  THE COST OF MAINTENANCE AND REPAIR SL-7N
C  MIS    =  MISCELLANEOUS COST SL-7
C  MISC   =  MISCELANEOUS COST DURING REFUELING $/DAY
C  MISN   =  MISCELLANEOUS COST SL-7N
C  NLN    =  THE COST OF THIRD PARTY NUCLEAR LIABILITY INSURANCE SL-7N
C  PAI    =  THE COST OF PROTECTION AND INDEMNITY INSURANCE SL-7
C  PAIN   =  THE COST OF PROTECTION AND INDEMNITY INSURANCE SL-7N
C  PU     =  THE PLANT UTILIZATION FACTOR
C  R      =  THE EFFECTIVE INCOME TAX RATE
C  RFC    =  THE REFUELING FACILITY COST $/DAY
C  RLC    =  THE REFUELING LABOR COST $/HR
C  RPC    =  THE REVENUE PER CONTAINER
C  SAS    =  THE COST OF STORES AND SUPPLIES SL-7
C  SASN   =  THE COST OF STORES AND SUPPLIES SL-7N
C  SFC    =  THE SHIP FORCE COST DURING REFUELING $/MAN-DAY
C  SSN    =  THE COST OF THE EXTRA SHOR STAFF REQUIRED FOR THE SL-7N
C  SWU    =  THE NUMBER OF SEPERATIVE WORK UNITS REQUIRED FOR INITIAL
C            ENRICHMENT
C  SWUD   =  THE NUMBER OF SEPERATIVE WORK UNITS REQUIRED TO ACHIEVE THE
C            DISCHARGE ENRICHMENT
C  TPH    =  THE TIME PAYMENT BEGINS FOR THE HULL SL-7
C  TPHN   =  THE TIME PAYMENT BEGINS FOR THE HULL SL-7N
C  TPM    =  THE TIME PAYMENT BEGINS FOR MACHINERY SL-7
C  TPMN   =  THE TIME PAYMENT BEGINS FOR MACHINERY SL-7N
C  TPRN   =  THE TIME PAYMENT BEGINS FOR THE REACTOR
C  VPY    =  THE NUMBER OF VOYAGES PER YEAR
C
```

```
      REAL*8 CH,CM,$CH/0.0/,$CM/0.0/,$TCC/0.0/,$CHN/0.0/,CHN,$CMN/0.0/,
     1CMN,$CRN/0.0/,CRN,$TCCN/0.0/,$RPY/0.0/,AFCN(25)/25*0.0/,RPYN(25)/
     225*0.0/,PVFFC/0.0/,$ACC/0.0/,ACC,PAI,$ACCN/0.0/,ACCN,$PAI/0.0/,
     3RPY(25)/25*0.0/,$RPYN/0.0/,$PAIN/0.0/,PAIN,HAM,HAMN,$HAM/0.0/,SSN,
     4$HAMN/0.0/,$NLN/0.0/,$SSN/0.0/,$MAR/0.0/,MAR,$MARN/0.0/,MARN,MISN,
     5$MIS/0.0/,MIS,$MISN/0.0/,$CE/0.0/,CE,$CEN,$SAS/0.0/,SAS,$SASN/0.0/
     6,SASN,SUB,SUBN,$AAO/0.0/,$AAON/0.0/,$TOC/0.0/,$TOCN/0.0/,CAOC,DAA,
     7TAOC(25)/25*0.0/,TAOCN(25)/25*0.0/,DAAT,AAC,CAOCN,DAAN,DAATN,AARN,
     8AAR,TDAN/0.0/,TDA/0.0/,TI(25)/25*0.0/,NP(25)/25*0.0/,TIN(25)/25*
     90.0/,NPN(25)/25*0.0/,TC(25)/25*0.0/,TCN(25)/25*0.0/,TDRC(25)/25*
     20.0/,DRC(25)/25*0.0/,AFNN(25)/25*0.0/,RPYNN(25)/25*0.0/,ACCNN(25)
     3/25*0.0/,CENN(25)/25*0.0/,AFFC(25)/25*0.0/,CHE/0.0/,AADRC/0.0/,
     4PVFC/0.0/,$TNP/0.0/,$TNPN/0.0/
      REAL T/0.0/,KK/0.0/,K/0.0/,AN/0.0/,AI/0.0/,AJ/0.0/,LC
   98 CRF(X,T)=X/(1.0-(1.0+X)**(-T))
      PWF(X,T)=(1.0+X)**(-T)
      ACC=2881274.0
      ACCN=2938899.0
      AUC=87773.87
      AUCD=24868.96
      AUE=87335.01
      AUF=11644.67
      B=.75
      BI=.09
      CB=3.88
      CCD=3.0
      CE=34.0
      CEN=5699200.0
      CF=78.40
      CH=28211000.0
      CHE=5699200.0
      CHN=31653000.0
      CLD=10950.0
      CM=26690000.0
      CMN=22883000.0
```

```
CPV=2192.0
CR=31.0
CRN=16000000.0
CS=6.0
CU=15.40
DT=20.0
ECB=.03
ECCO=.039
ECE=.034
ECF=-.02
ECL=.06
ECM=.03
ECR=-.01
ECS=.033
ECU=.036
ER=.12
LTV=6162.0
MAR=483000.0
MARN=613000.0
MIS=20000.0
MISC=713.14
MISN=20000.0
NLN=359670.0
R=.616364
RFC=1108.0
RLC=15.0
RPC=1433.0
PAI=115705.0
PAIN=118019.0
PU=.72
SAS=109500.0
SASN=127750.0
SFC=105.25
SSN=50000.0
SWU=5.22372
```

```
      SWUD=.743064
      TPH=-1.33
      TPHN=-1.75
      TPM=-1.75
      TPMN=-1.75
      TPRN=-4.0
      VPY=26.0
      X=BI*B+ER*(1.0-B)-BI*B*R
      AA=BI*B+ER*(1.0-B)
C  COMPUTE THE TOTAL COST OF CONSTRUCTION
C
C  COST OF THE HULL SL-7
      DO 2 I=1,4
      $CH=CH*.225*PWF(X,TPH)+$CH
      TPH=TPH+.5
      IF(TPH.GT.0.0)TPH=0.0
  2   CONTINUE
      TPH=1.0
      $CH=$CH+.1*CH*PWF(X,TPH)
C
C  COST OF MACHINERY SL-7
      DO 3 I=1,5
      $CM=$CM+CM*.18*PWF(X,TPM)
      TPM=TPM+.5
      IF(TPM.GT.0.0)TPM=0.0
  3   CONTINUE
      TPM=2.0
      $CM=$CM+.1*CM*PWF(X,TPM)
      $TCC=$CH+$CM
      DA=$TCC/DT
C
C  COST OF HULL SL-7N
      DO 4 I=1,5
      $CHN=$CHN+.18*CHN*PWF(X,TPHN)
      TPHN=TPHN+.5
```

```
      IF(TPHN.GT.0.0)TPHN=0.0
    4 CONTINUE
      TPHN=1.0
      $CHN=$CHN+.1*CHN*PWF(X,TPHN)
C
C  COST OF MACHINERY SL-7N
      DO 5 I=1,5
      $CMN=$CMN+.18*CMN*PWF(X,TPMN)
      TPMN=TPMN+.5
      IF(TPMN.GT.0.0)TPMN=0.0
    5 CONTINUE
      TPMN=2.0
      $CMN=$CMN+.1*CMN*PWF(X,TPMN)
C
C  COST OF THE REACTOR SL-7N
      DO 6 I=1,9
      $CRN=$CRN+.1*CRN*PWF(X,TPRN)
      TPRN=TPRN+.5
      IF(TPRN.GT.0.0)TPRN=0.0
    6 CONTINUE
      TPRN=2.0
      $CRN=$CRN+.1*CRN*PWF(X,TPRN)
      $TCCN=$CHN+$CMN+$CRN
      DAN=$TCCN/DT
C  COMPUTE THE ANNUAL REVENUE
      LC=1136.0/(365.0*PU)
      Z=25.0/LC
      NC=IFIX(Z)
      SL=NC*LC+.115+(NC-2)*.0767
      N=IFIX(SL)+1
      AN=N
      DO 7 I=1,N
      AI=I
      BZ=1.0
      IF(I.EQ.5.OR.I.EQ.10.OR.I.EQ.15.OR.I.EQ.20)BZ=.998
```

```
      IF(I.GT.SL)BZ=SL+1.0-N
      RPY(I)=RPC*CPV*VPY*BZ
      RPYNN(I)=RPC*CPV*VPY
      $RPY=$RPY+RPY(I)*PWF(X,AI)
      RPC=RPC*(1.0+ECM)
    7 CONTINUE
C
C   NUCLEAR FUEL COST
C   COMPUTE THE DIRECT COST OF FUEL PREPERATION
      CU=CU*(842.0/714.0)
      DO 8 II=1,NC
      IF(II.GT.2)ECF=0.0
      TFC=CF*AUF*PWF(ECF,-KK)
      TEC=CE*SWU*AUF*PWF(ECE,-KK)
      TCCO=CCO*AUC*PWF(ECCO,-KK)
      TCU=CU*AUC*PWF(ECU,-KK)
C
C   COMPUTE THE PRESENT WORTH AT START UP
      $TFC=TFC*PWF(X,-.5417)
      $TEC=TEC*PWF(X,-.9167)
      $TCCO=TCCO*PWF(X,-1.3333)
      $TCU=TCU*PWF(X,-1.3333)
      $CSU=$TFC+$TEC+$TCCO+$TCU
      M=IFIX(T)+1
      A=M-T
      T=T+LC
      KN=IFIX(T)+1
      K=KN
      KK=K-1
C
C   COMPUTE DIRECT REFUELING COST
      RT=28.0
      IF(II.EQ.1)RT=42.0
      IF(II.EQ.NC)GO TO 10
      TSFC=SFC*RT*PWF(ECL,-KK)*21.0
```

```
      TRLC=374.4*RT*PWF(ECL,-KK)*RLC
      TMISC=MISC*RT*PWF(ECM,-KK)
      TRFC=RFC*RT*PWF(ECM,-KK)
      TDRC(KN) =TRFC+TRLC+TSFC+TMISC
C
C  COMPUTE THE VALUE OF URANIUM AT SHUT DOWN
   10 $TCS=CS*CLD*PWF(X,.25)*PWF(ECS,-K)
      $TCR=CR*CLD*PWF(X,.4167)*PWF(ECR,-K)
      TECD=CE*SWUD*CLD*.99*PWF(ECE,-K)
      TCCOD=CCO*AUCD*PWF(X,-.417)*PWF(ECCO,-K)
      TCUD=CU*AUCD*PWF(X,-.417)*PWF(ECU,-K)
      $TVDU=(TECD+TCCOD+TCUD)*PWF(X,.8333)
C
C  COMPUTE THE VALUE OF PLUTONIUM AT SHUTDOWN
      TECEU=CE*SWU*1886.0*PWF(ECE,-K)
      TCCOE=CCO*1895.43*PWF(X,-.417)*PWF(ECCO,-K)
      TCUEP=CU*1895.43*PWF(X,-.417)*PWF(ECU,-K)
      TVPU=TECEU+TCCOE+TCUEP-.25*CF*1886.0*PWF(X,.375)*PWF(ECF,-K)
      TVPU=TVPU*1.46
      $TVPU=TVPU*PWF(X,.8333)
C
C   THE PRESENT WORTH OF THE FUEL AT SHUT DOWN
      $SVSD=$TVDU+$TVPU-$TCS-$TCR
C
C COMPUTE THE AVERAGE ANNUAL COST OF FUEL
      CRFS=CRF(X,LC)+(X*$SVSD)/($CSU-$SVSD)
      CRFST=CRFS/(1.0-R)-R/(LC*(1.0-R))
      AF=($CSU-$SVSD)*CRFST
      AFN=($CSU-$SVSD)*CRF(AA,LC)+AA*$SVSD
      DO 9 J=M,KN
      AJ=J
      AAJ=AJ-1.0
      IF(T.LT.J)A=T+1.0-J
      AFCN(J)=AFCN(J)+AF*A
      AFNN(J)=AFNN(J)+AFN*A
```

```
      PVFC=PVFC+AFCN(J)*PWF(X,AJ)
      RPYN(J)=RPYN(J)+RPYNN(J)*A
      ACCNN(J)=ACCNN(J)+ACCN*A*PWF(ECL,-AAJ)
      CENN(J)=CENN(J)+CEN*A*PWF(ECM,-AAJ)
      DRC(J)=DRC(J)+TDRC(J)*A
      A=1.0
    9 CONTINUE
      T=T+.0767
      IF(II.EQ.1)T=T+.0383
    8 CONTINUE
C
C  COMPUTE FOSSIL FUEL COST
      DO 11 I=1,N
      AI=I
      $RPYN=$RPYN+RPYN(I)*PWF(X,AI)
      BY=LTV*VPY*6.62
      BZ=1.0
      IF(I.EQ.5.OR.I.EQ.10.OR.I.EQ.15.OR.I.EQ.20)BZ=.998
      IF(SL.LT.I)A=SL+1.0-I
      AFFC(I)=CB*BY*A*BZ
      PVFFC=PVFFC+AFFC(I)*PWF(X,AI)
      CB=(1.0+ECB)*CB
C
C  COMPUTE THE ANNUAL OPERATING COST
      HAM=(10000.0+.007*(CH+CM))*A
      C=1.0
      IF(I.EQ.5.OR.I.EQ.10.OR.I.EQ.15.OR.I.EQ.20)C=.999
      ACC=ACC*C
      CHE=CHE*BZ
      SUB=(ACC+PAI+HAM+MAR+MIS+CHE+SAS)*A
      TAOC(I)=SUB+.13*SUB
      $TOC=$TOC+TAOC(I)*PWF(X,AI)
      HAMN=(10000.0+.007*(CHN+CMN+CRN))*A
      SUBN=ACCNN(I)+CENN(I)+(PAIN+HAMN+NLN+SSN+MARN+MISN+SASN)*A+TDRC(I)
      TAOCN(I)=SUBN+.13*SUBN
```

```
      $TOCN=$TOCN+TAOCN(I)*PWF(X,AI)
      ACC=ACC*(1.0+ECL)
      CHE=CHE*(1.0+ECM)
      PAI=PAI*(1.0+ECM)
      MAR=MAR*1.04
      MIS=MIS*(1.0+ECM)
      SAS=SAS*(1.0+ECM)
      PAIN=PAIN*(1.0+ECM)
      SSN=SSN*(1.0+ECL)
      MARN=MARN*1.04
      MISN=MISN*(1.0+ECM)
      SASN=SASN*(1.0+ECM)
   11 CONTINUE
C
C  COMPUTE THE AVERAGE ANNUAL COST
      CAOC=PVFFC+$TOC+686000.0
      CRFT=(CRF(X,DT)-R/DT)/(1.0-R)
      DAA=$TCC*CRF(AA,DT)
      DAAT=$TCC*CRFT
      AAC=CAOC*CRF(X,SL)+DAAT
      CAOCN=PVFC+$TOCN+1224000.0
      DAATN=$TCCN*CRFT
      AACN=CAOCN*CRF(X,SL)+DAATN
      DAAN=$TCCN*CRF(AA,DT)
C
C  COMPUTE THE AVERAGE ANNUAL REVENUE
      AAR=$RPY*CRF(X,SL)
      AARN=$RPYN*CRF(X,SL)
C
C  COMPUTE THE ANNUAL PROFIT AND LOSS
      DO 15 I=1,N
      AI=I
      IF(I.GT.DT)DA=0.0
      BBI=B*BI
      TI(I)=(RPY(I)-TAOC(I)-AFFC(I)-DA-($TCC-TDA)*BBI)
```

```
      TDA=TDA+DA
      NP(I)=TI(I)*(1.0-R)
      TC(I)=DAA+TAOC(I)+AFFC(I)
      IF(I.GT.DT)DAN=0.0
      TIN(I)=RPYN(I)-TAOCN(I)-AFNN(I)-DAN-($TCCN-TDAN)*BBI
      TDAN=TDAN+DAN
      NPN(I)=TIN(I)*(1.0-R)
      TCN(I)=DAAN+TAOCN(I)+AFNN(I)
C COMPUTE THE AVERAGE ANNUAL NET PROFIT
      $TNP=$TNP+NP(I)*PWF(X,AI)
      $TNPN=$TNPN+NPN(I)*PWF(X,AI)
      AAP=$TNP*CRF(X,SL)
      AAPN=$TNPN*CRF(X,SL)
 15    CONTINUE
      WRITE(6,102)
 102 FORMAT('1',T47,'THE ANNUAL PROFIT AND LOSS STATEMENT')
      WRITE(6,103)
 103 FORMAT('0','YEAR',T7,'SHIP',T14,'DEPRECIATION',T32,'OPERATING',
     1T48,'FUEL COST',T65,'REVENUE',T79,'TOTAL COST',T96,'TAXABLE',T111,
     2'NET PROFIT'/T14,'AMORTIZATION',T32,'EXPENSES',T96,'INCOME')
      M=10
      DO 20 I=1,N
      IF(I.GT.DT)DAA=0.0
      IF(I.GT.DT)DAAN=0.0
      WRITE(6,104)I,DAA,TAOC(I),AFFC(I),RPY(I),TC(I),TI(I),NP(I)
 104 FORMAT('0',T2,I2,T7,'SL-7',T14,F12.2,T30,F12.2,T46,F12.2,T62,F12.2
     1,T78,F12.2,T94,F12.2,T110,F12.2)
      WRITE(6,105)DAAN,TAOCN(I),AFNN(I),RPYN(I),TCN(I),TIN(I),NPN(I)
 105 FORMAT(' ',T7,'SL-7N',T14,F12.2,T30,F12.2,T46,F12.2,T62,F12.2,T78,
     1F12.2,T94,F12.2,T110,F12.2)
      IF(I.LT.M)GO TO 20
      WRITE(6,22)
 22   FORMAT('1')
      M=M+I+2
 20   CONTINUE
```

```
      WRITE(6,22)
      WRITE(6,106)AAC,AAR,AAP
  106 FORMAT('0','THE AVERAGE ANNUAL COST OF THE SL-7',T60,'=',F12.2/' '
     1,'THE AVERAGE ANNUAL REVENUE OF THE SL-7',T60,'=',F12.2/' ',
     2'THE AVERAGE ANNUAL NET PROFIT OF THE SL-7',T60,
     2'=',F12.2)
      WRITE(6,107)AACN,AARN,AAPN,LC
  107 FORMAT('0','THE AVERAGE ANNUAL COST OF THE SL-7N',T60,'=',F12.2/
     1' ','THE AVERAGE ANNUAL REVENUE OF THE SL-7N',T60,'=',F12.2/' ',
     2'THE AVERAGE ANNUAL NET PROFIT OF THE SL-7N',T60,
     3'=',F12.2/' ','THE LIFE OF THE CORE IN YEARS',T60,'=',F12.2)
      WRITE(6,22)
      STOP
      END
```

```
THE AVERAGE ANNUAL COST OF THE SL-7                          = 28861455.83
THE AVERAGE ANNUAL REVENUE OF THE SL-7                       =106248689.48
THE AVERAGE ANNUAL NET PROFIT OF THE SL-7                    = 30845480.00

THE AVERAGE ANNUAL COST OF THE SL-7N                         = 28731920.00
THE AVERAGE ANNUAL REVENUE OF THE SL-7N                      =104594249.83
THE AVERAGE ANNUAL NET PROFIT OF THE SL-7N                   = 30759100.00
THE LIFE OF THE CORE IN YEARS                                =        4.32
```

APPENDIX C

REFUELING SEQUENCE

REFUELING

The refueling sequence can be divided into the following phases:

Preparation - The reactor plant is shut down, cooled down, depressurized, and decay heat removal procedures are initiated. Required radiological containments and controls are established. The pressure vessel water level is lowered to the desired level. The containment closure head is unbolted and removed. The external parts of the control rod mechanisms are removed and the control rods are uncoupled from their drive mechanisms. Electrical leads to incore instrumentation and any other equipment that penetrates or is attached to the pressure vessel head is removed.

Reactor Vessel Head Removal - The hold down bolts and bolting ring are removed. A seal weld cutting machine is installed and the seal weld is cut. Radiological containment required for head removal is installed and the head removed to storage where the closure seal is renewed and any head restoration work performed.

Reactor Internals Removal - The control rod grid assembly is removed along with the core hold-down devices and baffles.

Fuel Transfer - The rotating index shield is installed on the reactor vessel flange. The fuel transfer cask is positioned over the index port, the fuel element is engaged and raised into the cask. The cask

closure door is shut, cooling water is connected to the cask if required, and the loaded cask is transferred to the storage pool where the fuel element is lowered into the pool. A new fuel element is raised into the cask, the cask transferred to the index shield and the fuel element lowered into the core. The sequence is repeated until fuel transfer is completed. The refueling equipment is then removed.

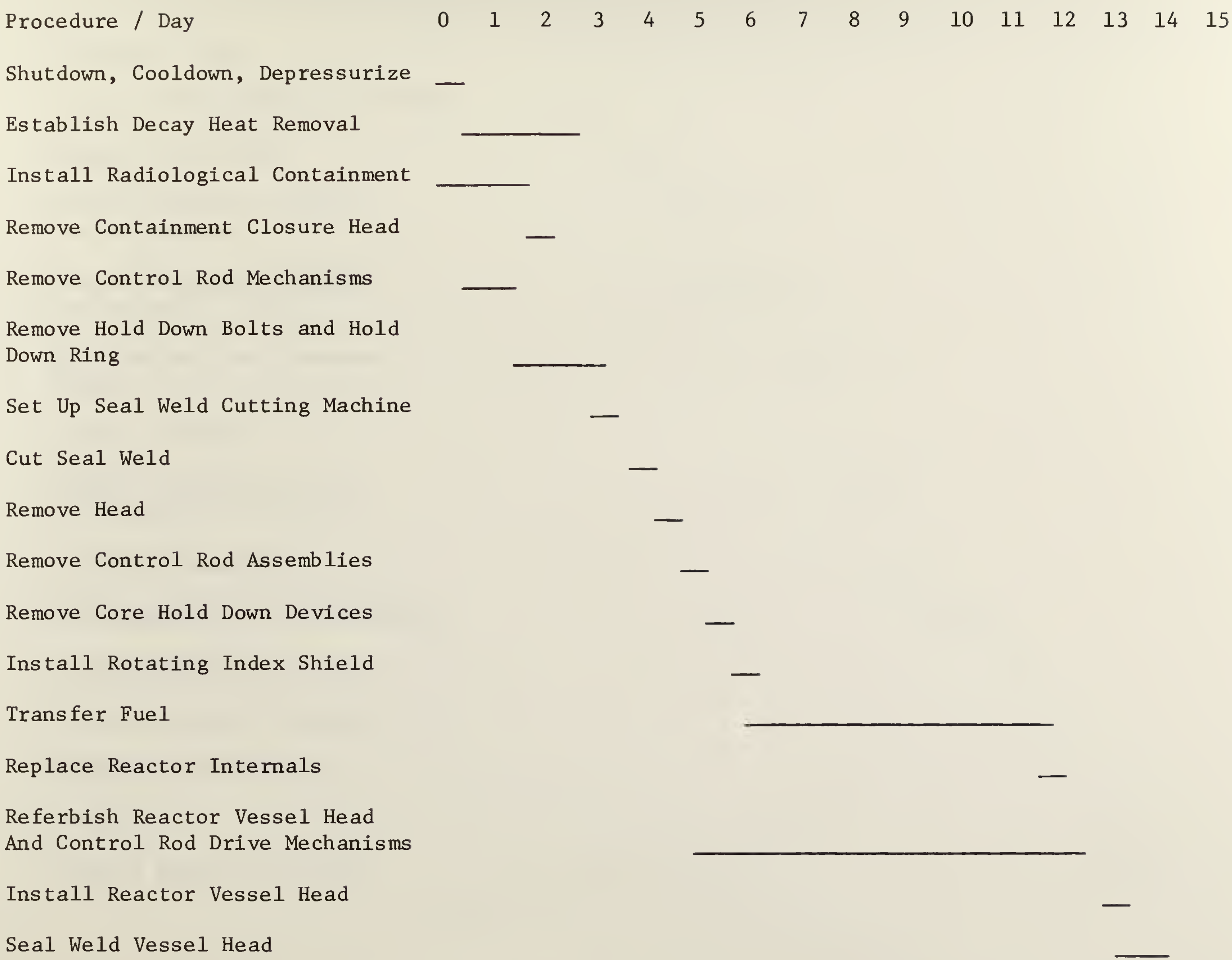
Reactor Internals Replaced - Those internals removed are now reinstalled.

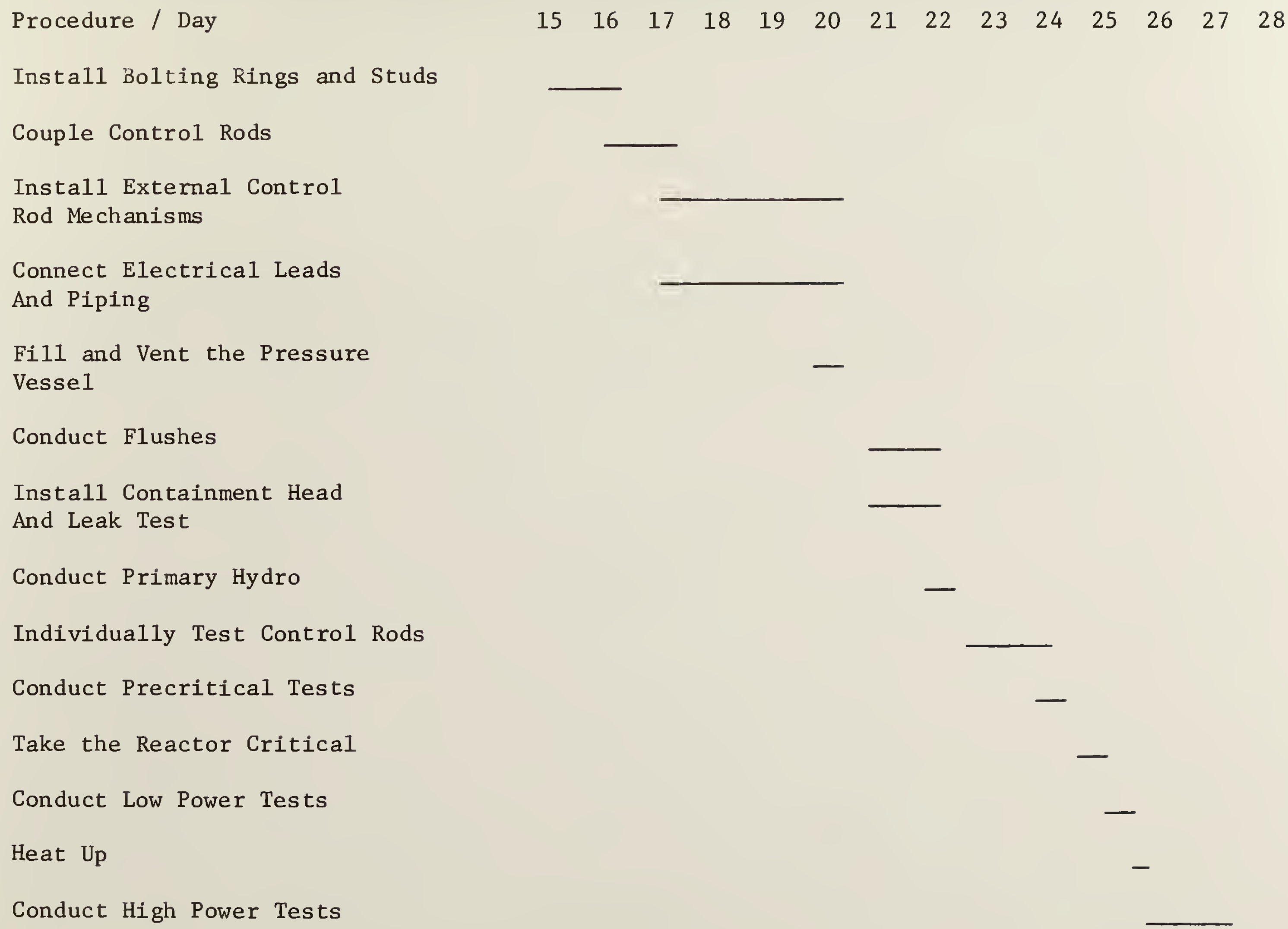
Reactor Vessel Head Replacement - The reactor vessel head is positioned on the reactor vessel and the head seal welded. The bolting ring is installed followed by the hold down studs.

Complete Reactor Preparations - The control rods are coupled to the lead screw and the rod drive mechanisms are reinstalled. Electrical leads and all other attachments to the pressure vessel head are completed. The containment head is installed and bolted.

Pre-Critical Tests - The pressure vessel is filled and vented. Any required flushes of piping are performed and the plant is hydrostatically tested. The containment vessel is leak tested. The control rods are individually tested.

Critical Tests - Take the reactor critical and perform low power physics tests. Heat up and perform high power tests.


Procedure / Day
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Shutdown, Cooldown, Depressurize
Establish Decay Heat Removal
Install Radiological Containment
Remove Containment Closure Head
Remove Control Rod Mechanisms
Remove Hold Down Bolts and Hold Down Ring
Set Up Seal Weld Cutting Machine
Cut Seal Weld
Remove Head
Remove Control Rod Assemblies
Remove Core Hold Down Devices
Install Rotating Index Shield
Transfer Fuel
Replace Reactor Internals
Referbish Reactor Vessel Head And Control Rod Drive Mechanisms
Install Reactor Vessel Head
Seal Weld Vessel Head


Procedure / Day
15 16 17 18 19 20 21 22 23 24 25 26 27 28
Install Bolting Rings and Studs
Couple Control Rods
Install External Control Rod Mechanisms
Connect Electrical Leads And Piping
Fill and Vent the Pressure Vessel
Conduct Flushes
Install Containment Head And Leak Test
Conduct Primary Hydro
Individually Test Control Rods
Conduct Precritical Tests
Take the Reactor Critical
Conduct Low Power Tests
Heat Up
Conduct High Power Tests